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JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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Operator's Corner

Sludge Digestion, Protective Coatings

FEBRUARY 1959—VOL. 31, No. 2

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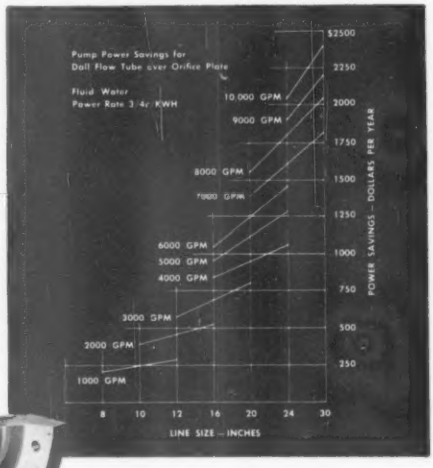

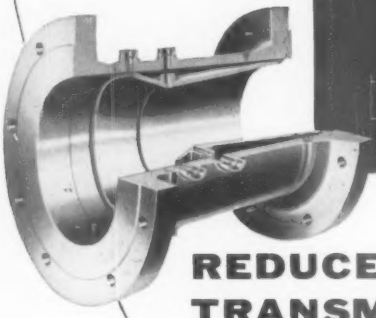

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 **February 1959** **Number 2**

Contents

Sewage Works

A Method of Starting High-Rate Digesters. By E. Alan Cassell and Clair N. Sawyer 123

Performance of Large Sewage Lagoons at Melbourne, Australia. By C. D. Parker, H. L. Jones, and N. C. Greene 133

Clogging Studies of Fine Bubble Diffuser Media. By Philip F. Morgan 153

Industrial Wastes

Development of the Anaerobic Contact Process. I. Pilot-Plant Investigations and Economics. By George J. Schroepfer and Norman R. Ziemke 164

Treatment of Wastes from Tall Oil Refining. By B. W. Dickerson, W. T. Laffey, and R. O. McNeil 191

Stream Pollution

Chromium-Induced Changes in the Blood of Rainbow Trout, *Salmo Gairdnerii*. By R. H. Schiffman and P. O. Fromm 205

Industrial Utilization of Municipal Wastewater. By C. H. Connell and E. J. M. Berg 212

The Operator's Corner

A Review of Sludge Digestion. By George T. Lohmeyer 221

Evaluating Protective Coatings. By Herman J. Estrada 235

Tips and Quips 239

News and Notes 241

Book Reviews 242

Proceedings of Member Associations

Oklahoma Water, Sewage and Industrial Wastes Conference 62a

Pacific Northwest Sewage and Industrial Wastes Association 64a

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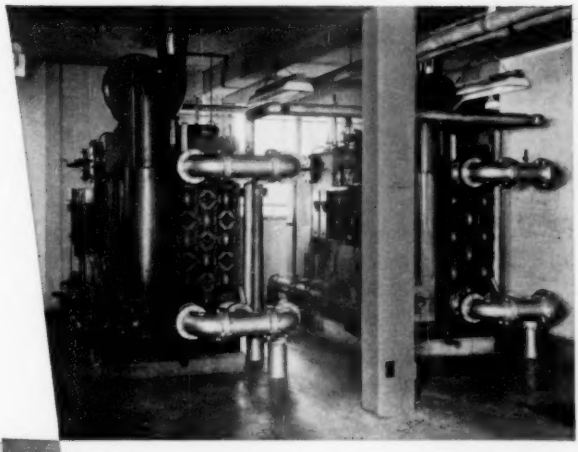

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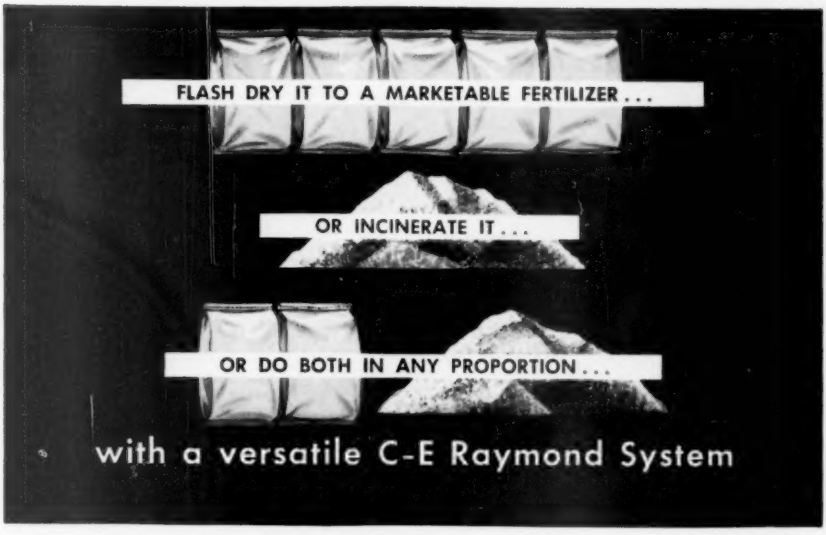

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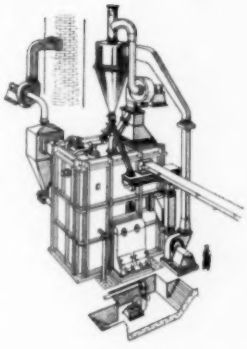

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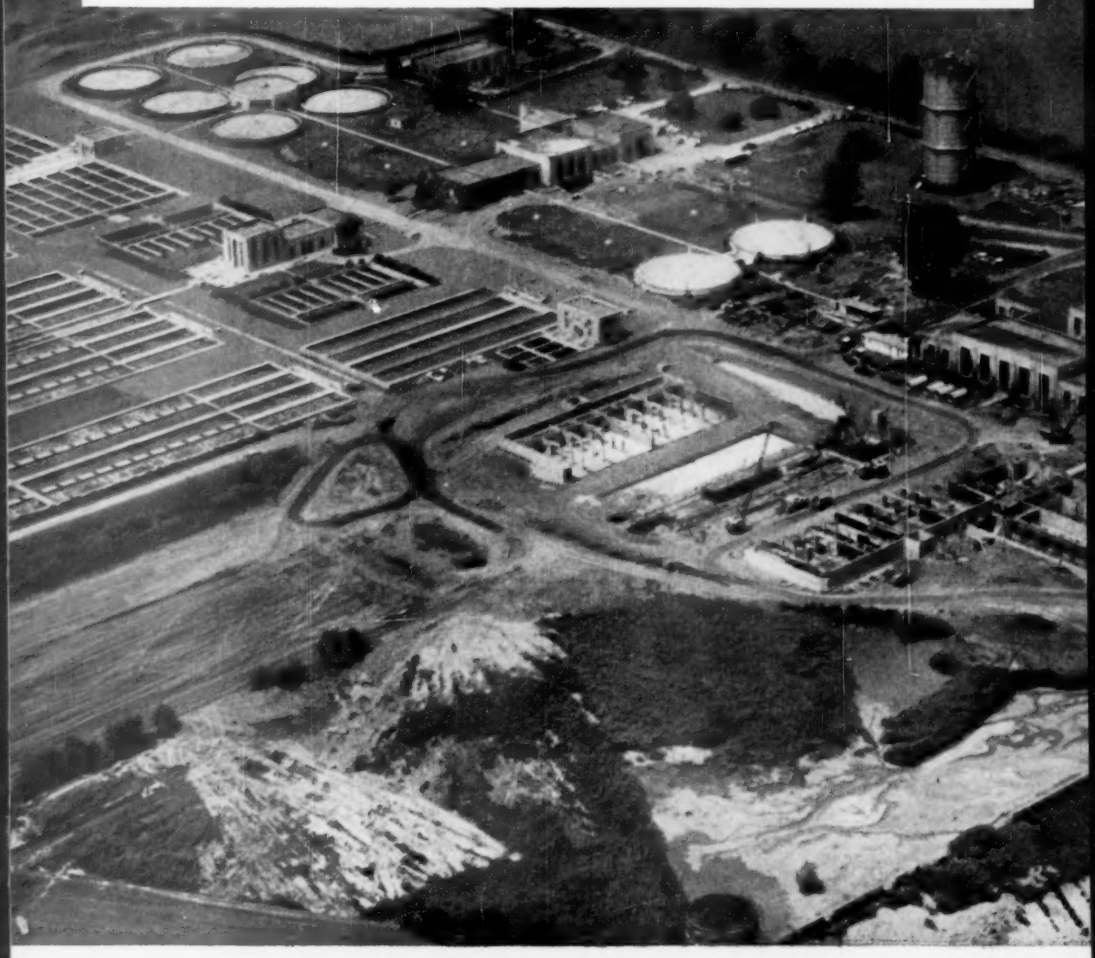

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Association	*Place*	*Time*
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Arkansas Water and Sewage Conf.	Marion Hotel Little Rock, Ark.	Mar. 16–18, 1959
Louisiana Conf. on Water Supply and Sewerage	Louisiana State Univ. Baton Rouge, La.	Mar. 18–20, 1959
Montana Sewage and Industrial Wastes Assn.	Jordan Hotel Glendive, Montana	Apr. 9–11, 1959
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Arizona Sewage and Water Works Assn.	Hi-Way House Hotel Phoenix, Ariz.	Apr. 16–18, 1959
Kansas Sewage and Industrial Wastes Assn. (*Change in Location*)	Besse Hotel Pittsburg, Kans.	Apr. 22–24, 1959
California Sewage and Industrial Wastes Assn.	Lafayette Hotel Long Beach, Calif.	Apr. 29– May 2, 1959
Iowa Sewage and Industrial Wastes Assn.	Roosevelt Hotel Cedar Rapids, Iowa	June 17–19, 1959

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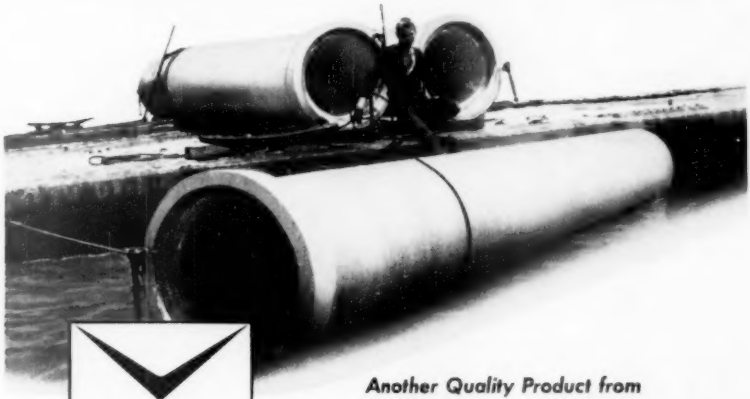

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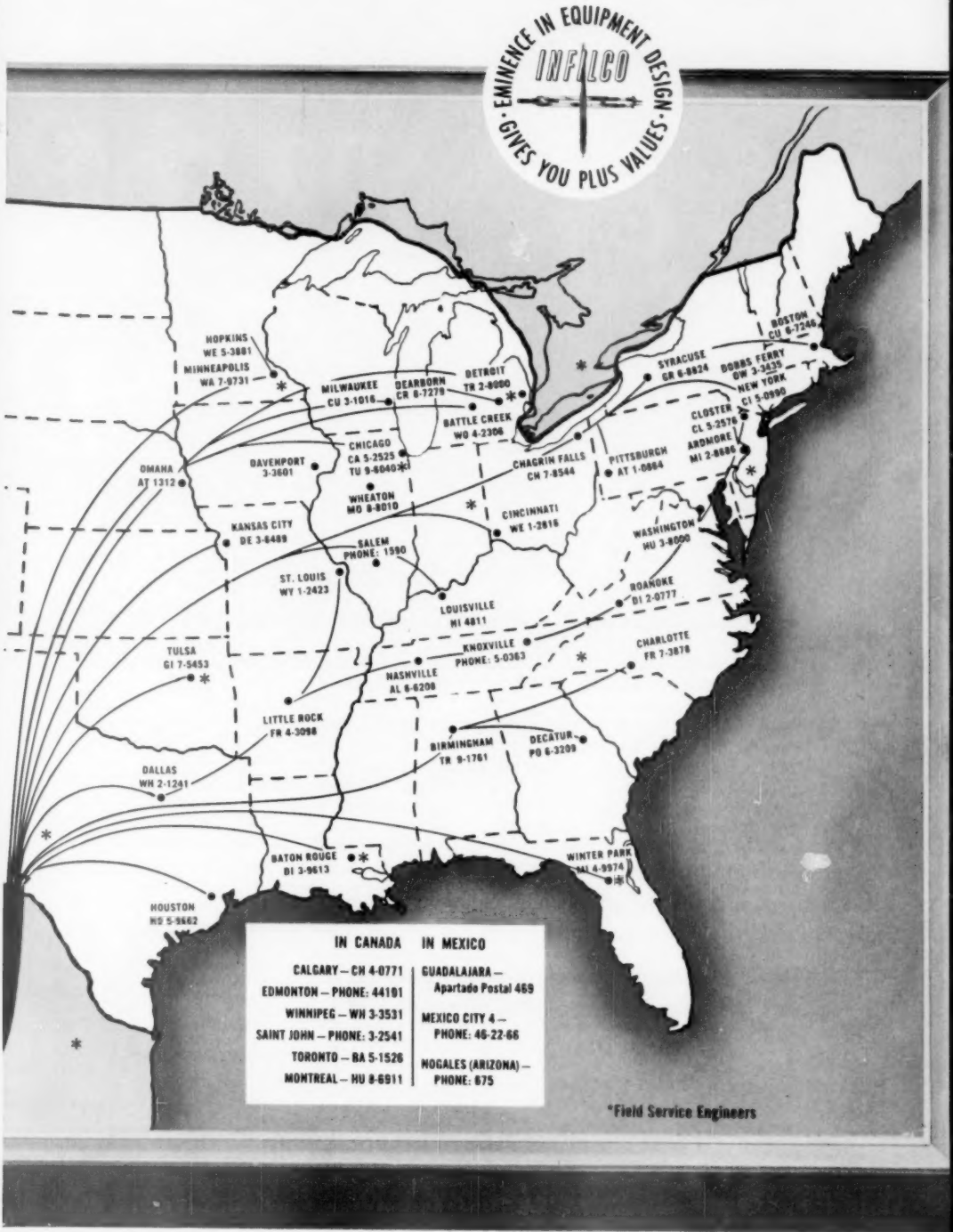

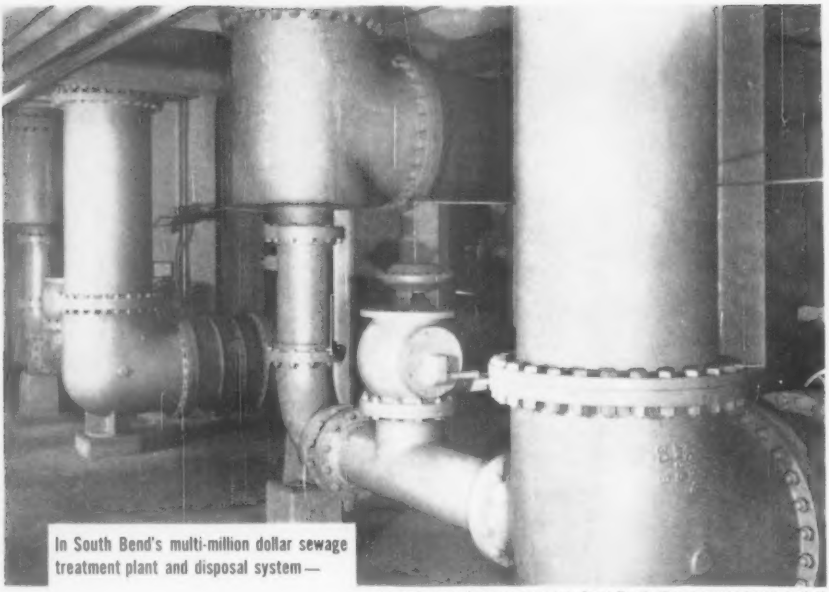

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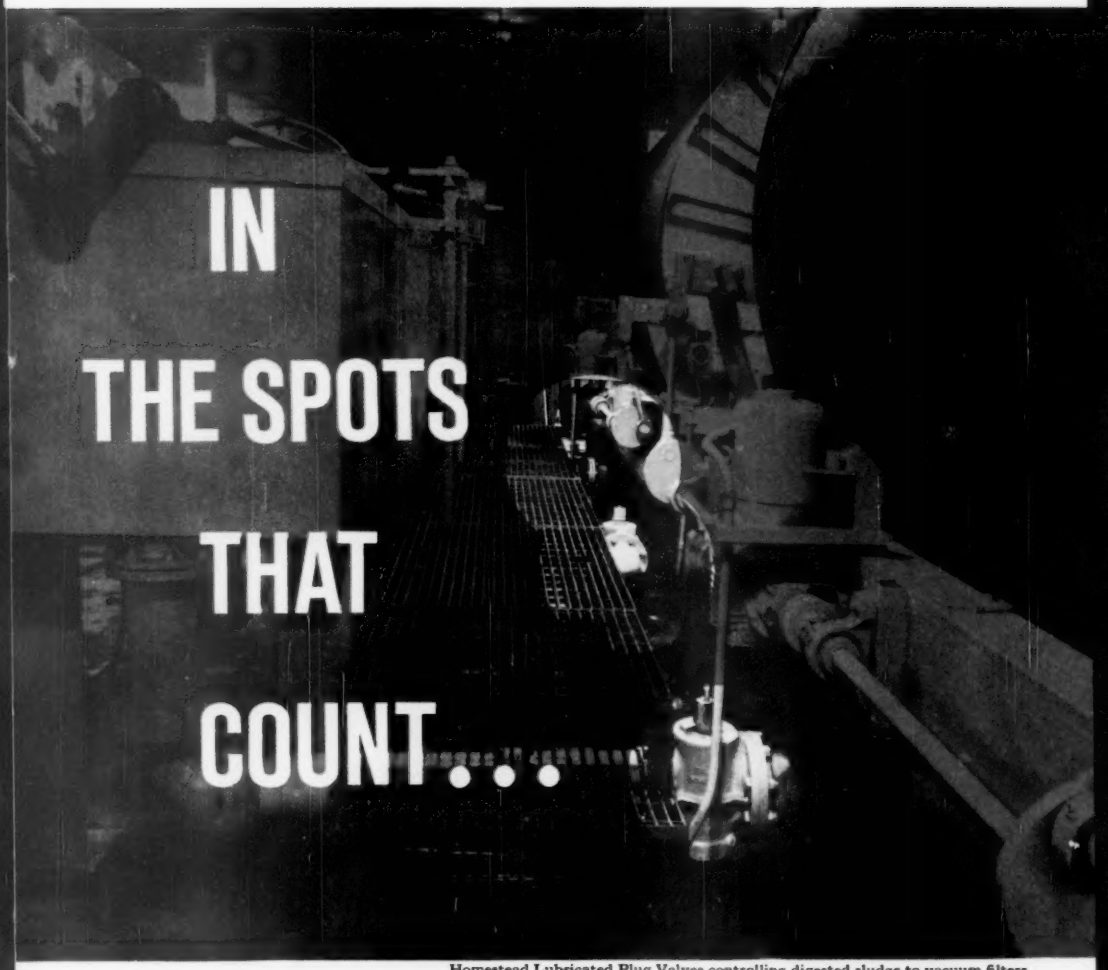

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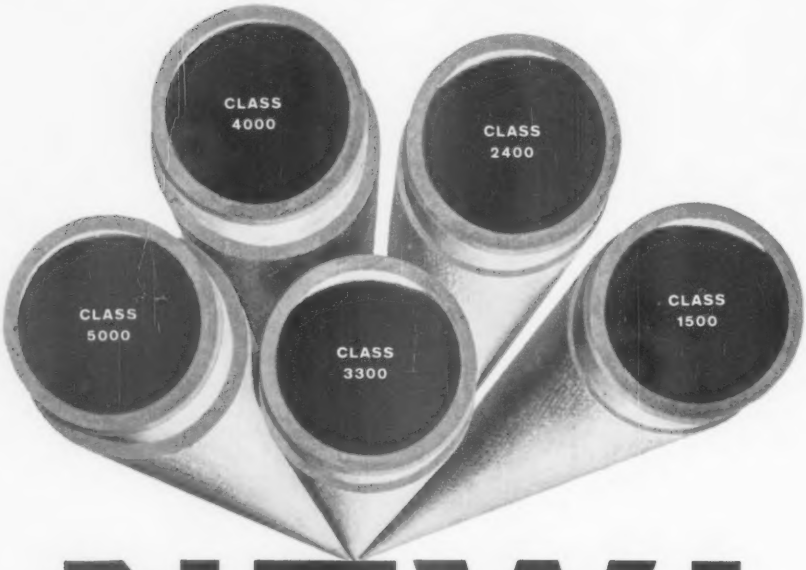

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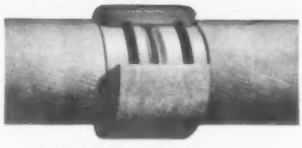

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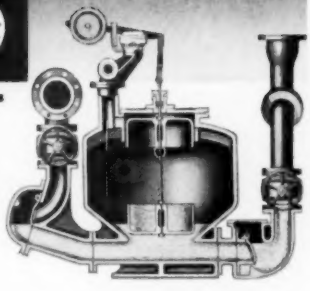

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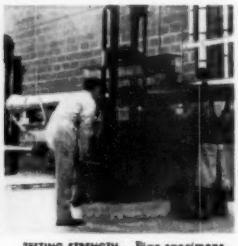

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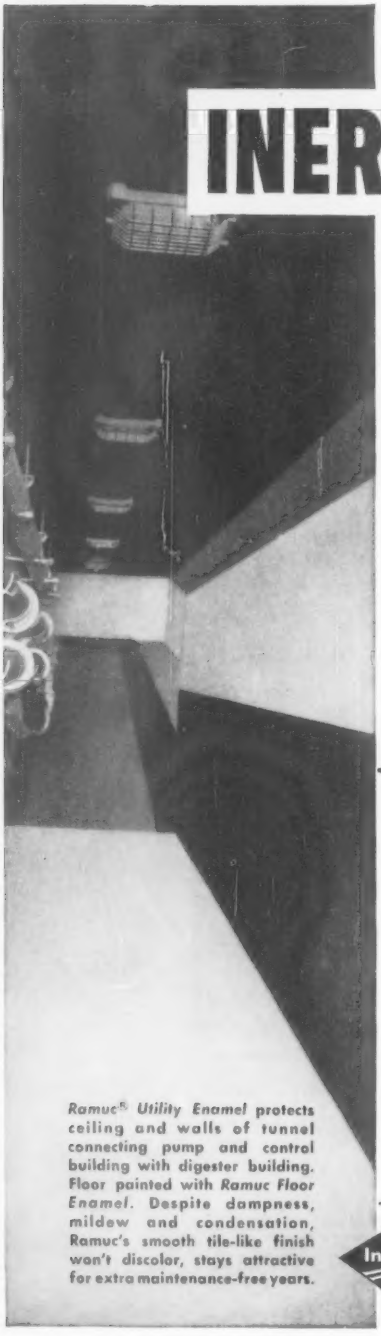

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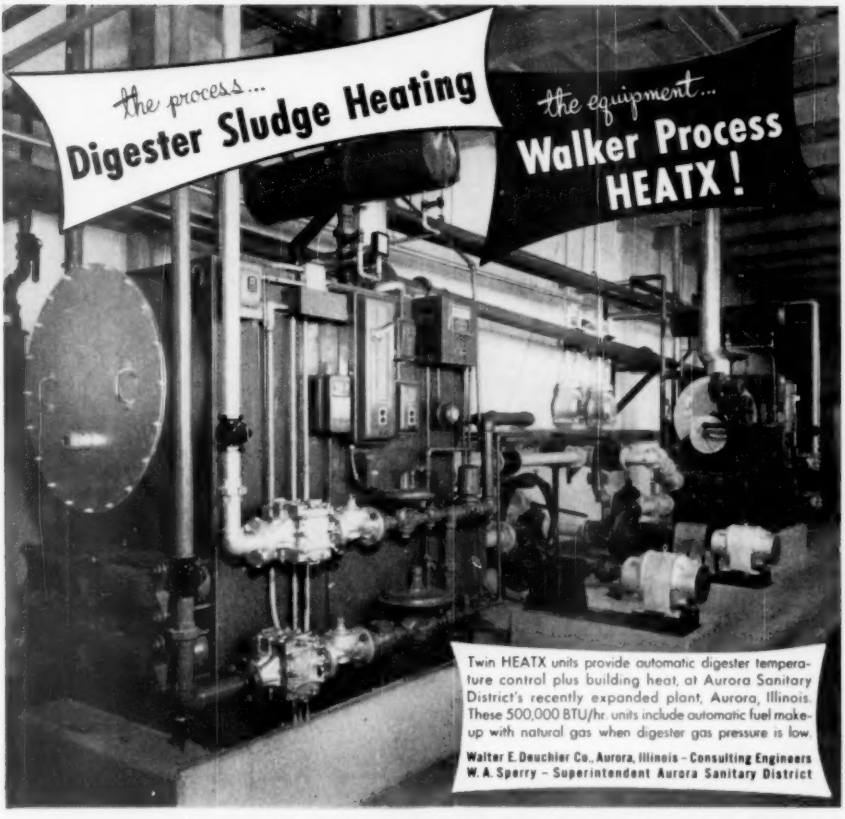
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Demand increases by the hour. By the time today's toddlers are grown, we'll need twice as much water.
Where will it all come from? Will you have enough? You'll find the answer below . . .
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This free booklet, "WATER—make sure you'll always have plenty," tells how to learn if you're running short, what to do if you are. Write Cast Iron Pipe Research Assn., Prudential Plaza, Chicago 1, Ill.
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Cast Iron Pipe Research Association promotes better understanding of water supply and distribution problems

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Similar advertising will appear regularly this year in *U. S. News & World Report, Nation's Business, Better Homes & Gardens, American Home* and *Sunset* magazines to carry this public service message to millions of community leaders and homeowners.

Free Local Plan-of-Action Booklet

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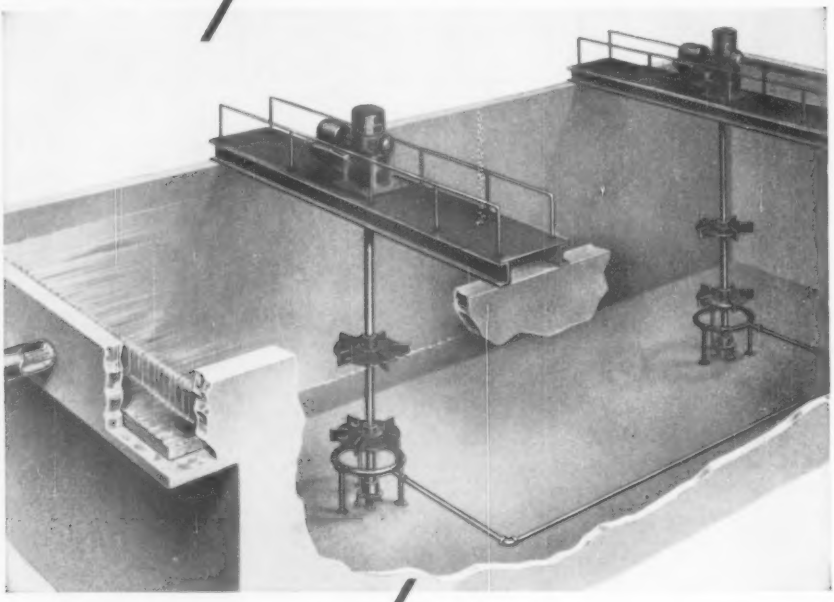

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Higher effective oxygen utilization—up to 50% compared with 5 to 6% in conventional systems—enables the new D-O Aerator to meet increased demands of the more concentrated activated sludges in today's biological sewage processes.

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Sewage Works

A METHOD OF STARTING HIGH-RATE DIGESTERS *

By E. Alan Cassell and Clair N. Sawyer †

Teaching Assistant and Professor of Sanitary Chemistry, Respectively, Massachusetts Institute of Technology, Cambridge, Mass.

Many difficulties have been experienced when attempting to initiate digestion in conventional digesters. Even greater difficulties would be expected to occur in high-rate digestion.

All high-rate digestion studies so far reported, whether laboratory, pilot plant, or plant scale, have been conducted with the benefit of ample seeding with digested sludge. Plant-scale operations conducted by Blodgett (1) were started with the tank two-thirds full of digesting sludge. In many new installations digested sludge is not readily available; therefore, information on how to initiate high-rate sludge digestion without benefit of seeding sludge is needed. Also, it is to be expected that regulatory agencies and designing engineers will welcome proof that high-rate digestion units can be placed into satisfactory operation within a reasonable time.

The studies reported in this paper were designed to investigate the possibility of starting high-rate digesters at detention times and solids loadings in the range of what might be expected at the beginning of the design period. A major objective was to determine whether a sustained load could be treated satisfactorily and yet allow the development of normal digestion while accommodating all sludge from a treatment plant. The study was restricted to a system employing only primary digesters; consequently, there was no opportunity to back-feed seeding sludge from secondary units. The use of primary digesters alone was considered to provide the most adverse conditions possible.

Experimental Plan and Procedure

For these studies, it was decided to use a sludge consisting of a mixture of raw and activated sludges. Such material was available at the sewage treatment plant at Leominster, Mass. It was further decided to use the sludge in the preliminary studies at the same solids concentrations as it occurred when collected from the sludge pumps.

Three separate studies were conducted consecutively, each series being used as the basis for those following. The investigations were conducted in the following order:

1. The Phase I study dealt with determining the minimum practical detention times which would allow the initiation of digestion both with and without pH adjustment.

2. The Phase II study was designed to find the most beneficial additive for pH adjustment during the initial stages of sludge digestion.

* Presented at the 1958 Spring Meeting, New England Sewage and Industrial Wastes Assn.; Gardner, Mass.; June 4–5, 1958.

† At present, Associate and Director of Research, Metcalf and Eddy, Boston, Mass.

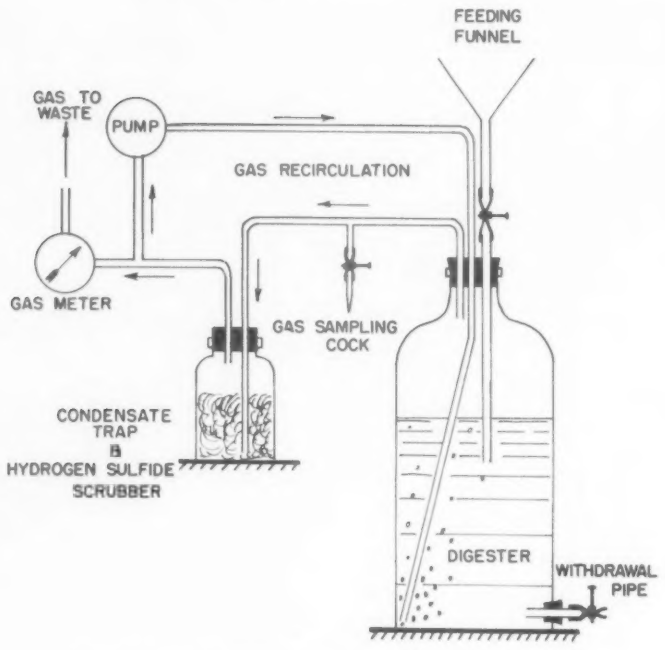

FIGURE 1.—Schematic layout of sludge digestion units.

3. The Phase III study was to determine the effect of solids loading on starting digesters when the pH was controlled.

The three studies were conducted with laboratory digesters maintained at a temperature of 33 to 35°C and having effective capacities of eight liters. The digester contents were continuously mixed by gas recirculation to maintain a mixed liquor condition at all times. Sludge additions and withdrawals were made through special inlets and outlets in a manner which minimized the entrance of air into the system. Figure 1 shows a schematic diagram of the laboratory digesters.

Supplies of primary sludge consisting of the raw and activated sludge mixture were collected at about two-week intervals. The sludge was stored at 4°C and before feeding it was warmed to about 35°C.

All digesters were initially filled with raw sewage and, after one day had elapsed, attained operating temperature (33–35°C). As soon as the operating temperature was reached, daily additions of raw sludge were started and maintained for the duration of each study. Sludge mixtures were withdrawn daily from all digesters in volumes equal to the raw sludge fed immediately before charging the raw sludge to the digesters.

All analyses were conducted in accordance with "Standard Methods" (2).

Experimental Results

Phase I

Four laboratory digesters were fed different volumes of identical raw sludge to allow theoretical detention times of 10, 15, 20, and 30 days to be studied. The full daily quota of raw sludge was fed from the first day until the end of the study. The sludge was

fed as obtained from the sewage treatment plant source, with no attempt being made to control the variations in solids concentration. The characteristics of the raw sludge are presented in Table I.

Within 10 days after the first sludge addition, the pH values of all digesters were below 6.0 (Figure 2). Within 20 days the volatile acids concentration had built up and stabilized at concentrations varying from 2,000 to 4,000 mg/l as acetic acid. Highest volatile acids concentration was observed in the digesters with the lowest detention times. Only small quantities of gas were produced.

The daily feeding schedule was maintained for 52 days in the digesters with detention times of 10 and 20 days, and for 83 days in the digesters with detention times of 15 and 30 days. The "sour" condition which developed during the first 10 days persisted for the duration of the study. Thus, under conditions of complete mixing, it appeared that the minimum detention time required for the initiation of sludge digestion without the benefit of pH control was in excess of 30 days when full loading was maintained.

Calcium hydroxide was added for pH control to the 10- and 20-day detention time digesters on the 52nd day. Unfortunately, twice the quantity of lime required to adjust the pH to 7.0 was added. The results obtained were felt to be inconclusive; however, there were some indications that a detention time of 20 days was about the minimum which would allow starting a digester under favorable pH conditions.

In actual practice, digesters are overdesigned for present needs, in anticipation of increasing quantities of sludge in the future. A high-rate digester designed for an ultimate 10-day detention time would probably provide a detention time of approximately 20 days when first put into operation. This consideration, coupled with the

TABLE I.—Raw Sludge Characteristics in Phase I Study

Period Covered (days from beginning)	pH	Total Solids (per cent)	Volatile Solids (per cent)
1–13	5.6	2.72	70.3
14–21	5.7	1.91	83.5
22–29	5.3	3.10	81.5
30–42	5.3	2.68	85.5
43–46	5.3	4.00	78.4
47–59	5.3	2.82	79.1
60–74	5.3	2.57	73.9
75–83	5.5	2.68	77.7
Weighted Avg	—	2.74	79.3

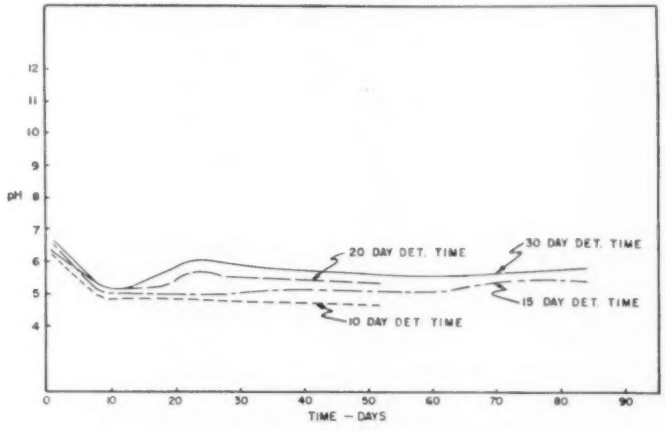

FIGURE 2.—pH trends in Phase I studies.

results obtained in the Phase I studies, resulted in a decision to conduct the remaining studies on digesters with 20-day detention times.

Phase II

Four laboratory digesters were filled with sewage and fed volumes of identical sludge to provide detention times of 20 days. As was the case in the Phase I studies, no attempts were made to control the solids variation in the raw sludge. The characteristics of the raw sludge are presented in Table II.

Additions of various alkaline agents were made to maintain the pH between 6.7 and 7.2 in three digesters. pH control was maintained by use of the following alkaline agents:

1. High calcium lime ($Ca(OH)_2$).
2. High magnesium lime (36-per cent MgO).
3. Ammonium hydroxide.

The fourth digester, in which no pH adjustments were made, served as a control. Approximately 10 days after feeding was initiated, the control digester was sour and remained in this condition for the duration of the study.

During the early period the volatile acids concentration (Figure 3) increased rapidly in all digesters. In the control digester, volatile acids continued to increase throughout the study. This was also the case in the digester whose pH was controlled with ammonium hydroxide. In the other two digesters, however, a maximum concentration of volatile acids was reached in approximately 18 days and then a rapid decline occurred. This decrease was accompanied by a rapid increase in gas production as shown in Figure 4.

Gas production continued to increase slowly in both digestion units in which pH was controlled with the addition of lime, and a greater production occurred in the one treated with high-calcium lime. Volatile acids continued to decline in both digesters un-

TABLE II.—Raw Sludge Characteristics in Phase II Study

Period Covered (days from beginning)	pH	Total Solids (per cent)	Volatile Solids (per cent)
1–4	5.4	4.40	74.3
5–10	5.4	3.00	75.4
11–20	5.4	2.86	74.5
21–28	5.4	2.64	73.7
29–48	5.5	2.74	81.0
Weighted Avg	—	2.92	77.0

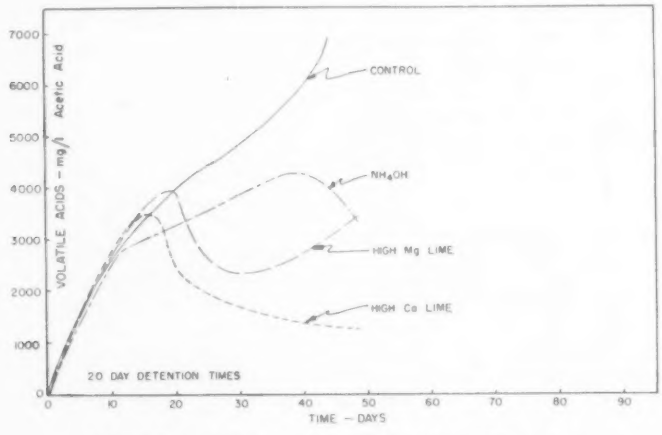

FIGURE 3.—Volatile acids trends in Phase II studies.

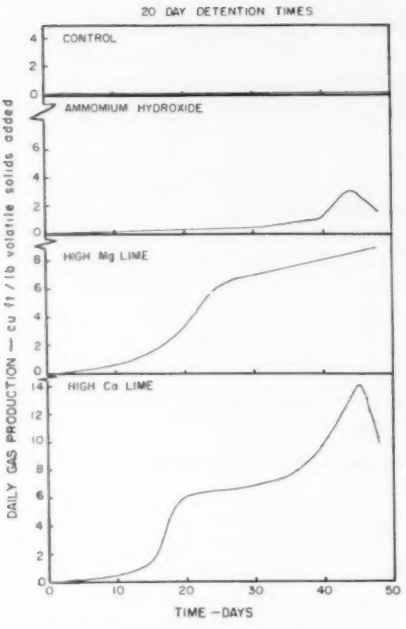

FIGURE 4.—Daily gas production in Phase II studies.

til the 30th day when they began to increase again in the digester treated with high-magnesium lime.

Table III shows the composition of the gases produced by the digesters in which pH was controlled with the use of regular and high-magnesium lime. It will be noted that a burnable gas was produced by both digesters. Only negligible amounts of gas were produced by the control digester and the digester receiving ammonium hydroxide for pH control.

TABLE III.—Sludge Gas Composition from Phase II Study

Neutralizing Agent	Gas (per cent)				
	CO_2	O_2	H_2	CH_4	N_2
High-calcium lime (35th day)	33	1.5	0.5	58.9	6.1
High-magnesium lime (36th day)	36.8	0.8	0.0	58.0	4.4

After 48 days of operation, the only unit indicating the approach of normal digestion was the digester in which pH had been controlled by the addition of high-calcium lime. Of the three alkaline agents studied, high-calcium lime appeared to be the most beneficial in aiding the initiation of sludge digestion.

Phase III

Four digesters were operated at detention times of 20 days. By concentrating a common stock of raw sludge it was possible to vary the solids concentrations of the sludge fed to each digester. The digesters were fed raw sludges of concentrations of 2.0, 4.0, 6.0, and 2.0 per cent (unlimed control), respectively in the four digesters. The corresponding solids loadings are presented in Table IV.

TABLE IV.—Solids Loadings in Phase III Studies

Total Solids* (per cent)	Volatile Solids Loading (lb/day/cu ft)
2	0.054
4	0.108
6	0.162

* Avg VS = 86.5 per cent.

Additions of calcium hydroxide were made to the digesters fed 2.0-, 4.0-, and 6.0-per cent sludges to maintain the pH between 6.8 and 7.2. The remaining digester which was fed 2.0-per cent sludge was maintained as a control in which no pH adjustment was made. Within 8 days the pH of the control fell to 5.0, indicating acid conditions had become established. The control digester remained sour for the duration of the study, a total of 95 days.

Final calcium hydroxide additions were made on the 29th day to the 2.0- and 4.0-per cent sludge digesters and on the 45th day to the digester with 6.0-per cent sludge. The total amount

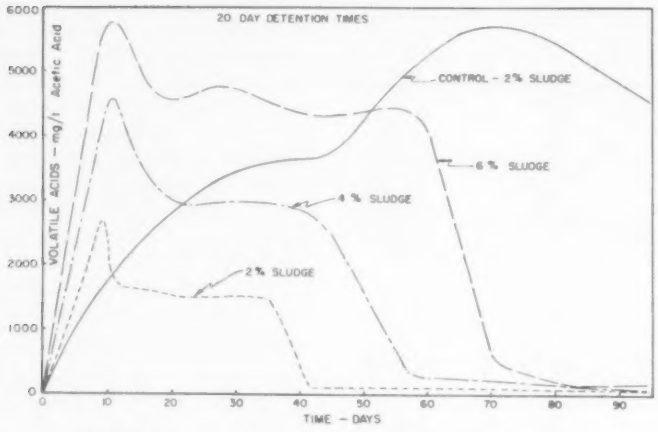

FIGURE 5.—Volatile acids trends in Phase III studies.

of lime added to each digester was as follows:

Solids in Sludge Fed (per cent)	Total Lime Added (lb/100 cu ft digester volume)
2.0	33.8
4.0	60.4
6.0	86.8

The three digesters to which calcium hydroxide was added exhibited strikingly similar patterns. These patterns become apparent when the volatile acids trends (Figure 5) and the daily gas production (Figure 6) are considered. Over the initial 10 days, all digestion mixtures were characterized by a rapid rate in the build-up of volatile acids coupled with a relatively slow increase in gas production. Within 10 days the maximum volatile acids concentration was reached. By this time gas production had attained a value which resulted in an immediate decrease in the volatile acids concentration. The volatile acids were reduced to about two-thirds of the maximum concentration and gas production

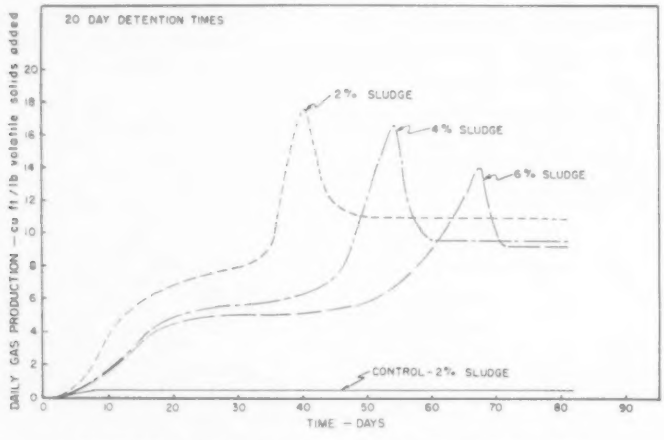

FIGURE 6.—Daily gas production in Phase III studies.

rose to about one-half of what is expected in normal digestion.

The digesters continued to operate for at least two weeks in an apparent state of equilibrium with only slight increases in gas production and slight decreases in volatile acids being noticed. Then, gasification began to increase rapidly until gas production was considerably higher than found in digesters operating normally. At this time, volatile acids began to decrease very rapidly. As soon as the volatile acids concentration reached approximately 200 mg/l, gas production decreased to about 10 cu ft/lb of volatile solids added, or approximately the rate obtained in normal digestion. All tests indicated that normal digestion had become established.

Analyses of the gases (Table V) produced by the digesters fed 2.0-, 4.0-, and 6.0-per cent sludges were conducted on the 81st day. Burnable gases of similar quality were produced by the three digesters.

The time required to establish normal digestion increased with the concentration of the sludge fed to the unit. It required 41, 55, and 73 days, respectively, for the 2.0-, 4.0-, and 6.0-per cent sludges. The solids loading was the only difference between the three digesters. Higher solids loadings were found to produce higher concentrations of volatile acids and evidently it was the volatile acids concentration which determined the time required for the development of normal digestion.

TABLE V.—Gas Composition in Limed Digesters in Phase III Study*

Digester Identification (per cent raw sludge fed)	Gas (per cent)				
	CO_2	O_2	H_2	CH_4	N_2
2.0	33.3	0.6	0.1	60.0	6.0
4.0	37.0	0.6	0.4	58.0	4.0
6.0	35.4	0.7	0.0	57.2	6.7

* 81st day of study.

TABLE VI.—Grease Analyses from Phase III Study

Solids in Sludge Fed (per cent)	Grease (per cent of total solids in digested sludge)	
	32nd Day	81st Day
2*	21.5	21.0
2	12.9	8.0
4	21.1	8.8
6	23.5	9.1

* Control.

Grease analyses were conducted on the contents of all four digesters on the 32nd and 81st days of the study. The results are shown in Table VI. Very little grease destruction was observed in the control. Substantial grease destruction did not occur in any of the digestion units until normal digestion had been attained.

Discussion

Digestion was successfully initiated with volatile solids loadings as high as 0.162 lb/day/cu ft when the pH was controlled in a favorable range with lime and a detention time of 20 days was maintained. A correlation between the trends of volatile acids and gas production observed in the Phase III studies is presented in Figure 7. When careful consideration is given to these trends, further insight into the mechanism of sludge digestion can be obtained. The first relatively rapid increase in gas production occurred about 10 days after the units were started and was responsible for the initial decrease in volatile acids concentration. The volatile acids decreased and leveled off at values considerably higher than occur during normal digestion. Likewise, a stabilization in the rate of gas production occurred at a rate approximating one-half that found during normal digestion. This condition persisted for about three weeks in the 2.0- and 4.0-per cent sludge digesters and for about six weeks in the one fed 6.0-per

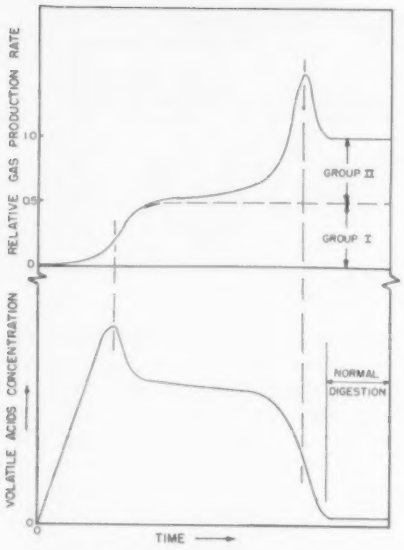

FIGURE 7.—Development of the methane bacteria during initiation of sludge digestion.

cent sludge. During this period a relatively poor quality gas was produced; for example, on the 32nd day, carbon dioxide content was 36.6, 41.2, and 43.8 per cent, respectively, in the gas from the 2.0-, 4.0-, and 6.0-per cent sludge digesters. The gas from the digester fed 6.0 per cent sludge showed 46.8 per cent methane on the same day. This provided proof that at least one group of methane forming bacteria was well established under the prevailing high concentrations of volatile acids on that day.

Gas production gradually increased in all digesters following the 15th day and began to increase rapidly at about 33, 46, and 58 days, respectively, in the units receiving 2.0-, 4.0-, and 6.0-per cent sludges. It was not until the final upsurge in gas production occurred that the volatile acid content of the digesting mixtures fell to what is considered normal levels and gas quality improved to the usual standards.

From the results obtained in these studies, it is concluded that the methane producing bacteria may be divided into two groups. The first group is relatively resistant to high volatile acids content and multiplies rather rapidly. Under reasonably favorable pH conditions, they increase rapidly enough to produce significant amounts of methane in 10 to 15 days. In the Phase III studies, Group I methane formers were considered to be largely responsible for gas production until the time the final upsurge in gasification occurred (Figure 7). The second group of methane formers is quite slow in multiplying or is adversely affected by high concentrations of volatile acids. The sharp increases in gas production following the 33rd, 46th, and 58th days in the various digesters were, undoubtedly, caused by Group II organisms reaching a state in their log growth phase which was detectable by gas production measurements. The high rate of gas production persisted until volatile acids concentrations were reduced to normal levels.

The results of these studies indicate that the Group II methane organisms determine the length of time required for the development of normal digestion and are, probably, the organisms which cause the majority of the problems associated with sludge digestion because of their extremely slow growth rate. The data also lead to the conclusion that the Group II methane formers are primarily responsible for conversion of volatile acids (at least certain forms of the volatile acids) to methane. Group I methane formers are apparently quite selective in the materials they can convert to methane but, fortunately, are relatively hardy and possess high reproductive rates.

The higher solids loadings required longer periods of time for the development of normal digestion. As the pH was maintained constant, ir-

respective of the solids loading, the only difference observed between the three digesters of the Phase III studies was the volatile acids concentration. Evidently the higher volatile acids concentrations associated with higher solids loadings exhibited some inhibitory effect on the Group II organisms. The fact that normal digestion did not develop in the Phase I studies, even though the volatile acids concentrations remained lower than observed in the Phase III studies, indicates that pH remains the primary practical consideration during the initiation of sludge digestion.

The time required for initiation of partial and normal digestion at the various volatile solids loadings is shown in Figure 8. It will be noted that the time for development of both partial and normal digestion increased with solids loadings. The approximate ranges of solids loadings maintained while starting conventional digesters by the methods recommended by Schlenz (3)(4) and by Van Kleeck (5) are also indicated on Figure 8. The solids ranges were determined on the assumption that the average maximum loading of volatile solids in conventional digesters was 0.07 lb/day /cu ft.

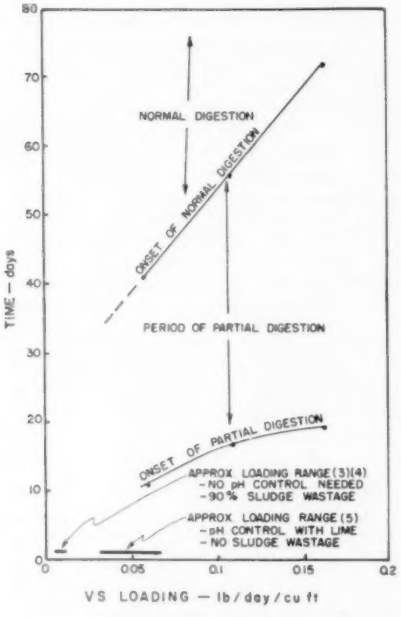

FIGURE 8.—Effect of solids loading on required time for development of partial and normal digestion.

The findings in these studies appear to be in conflict with Schlenz who recommended charging small portions of the daily raw sludge accumulation without any lime additions during the initial stages of digestion, thus limiting the volatile acids production. Actually, this represents an effective method of pH control which eliminates the necessity of pH adjustment with lime; however, it is at the expense of not being able to accommodate the entire quantity of raw sludge available to the digesters during the initial phases.

Van Kleeck (5) has been associated with many instances in which digestion has been initiated in digesters receiving the entire daily production of raw sludge. Problems were eliminated merely by controlling the pH with additions of lime. The method used to initiate sludge digestion in the studies reported in this paper was identical to the method recommended by Van Kleeck. This method has been shown to be applicable to high-rate digesters operating on a 20-day detention period in which solids loadings were approximately three times as great as usually encountered in conventional digestion.

The method used and recommended is outlined as follows:

1. Fill digester with sewage.
2. After a temperature of 95°F has been attained, start adding sludge in amounts which will provide about 20 days detention time (at minimum) and at volatile solids loadings which do not exceed 0.15 lb/day/cu ft.
3. Add lime as often as necessary

to maintain the pH between 6.8 and 7.2.

4. Provide efficient mixing of entire digester contents throughout the initial phases of digestion. Continuous mixing is preferable.

Conclusions

1. Laboratory studies have shown it is possible to initiate sludge digestion with raw sludge alone in high-rate digesters with 20-day detention time maintained under volatile solids loadings as great as 0.162 lb/day/cu ft, provided that the pH is maintained between 6.8 and 7.2 by liming.

2. With a 20-day detention time, approximately 40, 50, and 65 days, respectively, will be required for the development of normal digestion in high-rate digesters when feeding 2.0-, 4.0-, and 6.0-per cent sludges, or volatile solids loadings of 0.054, 0.108, and 0.162 lb/day/cu ft.

3. Total lime requirements for maintaining pH will vary with the solids loading. With the sludge used in these studies, 33.8, 60.4, and 86.8 lb were used per 100 cu ft of digester capacity, respectively, for the 2.0-, 4.0-, and 6.0-per cent sludges.

4. With no pH adjustment, normal digestion did not develop in high-rate digesters with 30-day detention times and volatile solids loadings of 0.045 lb/day/cu ft.

5. Evidence was obtained which indicates that methane formation is accomplished by the action of two distinct groups of methane bacteria. The Group I organisms are capable of rapid multiplication but appear to be highly selective in type of organic compounds they can convert to methane. The Group II organisms are extremely slow growers and appear to be particularly adapted to the destruction of certain volatile acids.

6. The methane organisms comprising Group II are limiting during initiation of digestion. The growth rate of Group II appeared to be inhibited by high concentration of volatile acids.

7. Maintenance of optimum pH conditions remains the factor of primary practical importance during the initiation of sludge digestion.

Acknowledgment

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1959 NUCLEAR CONGRESS

The 1959 Nuclear Congress, sponsored by more than 30 leading engineering, scientific, and management groups, including the Federation, is scheduled to be held April 5–10 in the Public Auditorium, Cleveland, Ohio. Within the program will be two half-day technical sessions devoted to water and waste disposal problems. Copies of the advance programs are available from the Federation office on request.

PERFORMANCE OF LARGE SEWAGE LAGOONS AT MELBOURNE, AUSTRALIA

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The use of lagoons or oxidation ponds to purify sewage is receiving increasing attention as a simple and satisfactory form of treatment under suitable conditions. A great many installations have been described and a number of fundamental studies have been reported. The literature has been reviewed recently by Fitzgerald and Rohlich (1). This paper reviews the performance of the Melbourne lagoons over a period of years and details practical experiences associated with their operation.

Experimental Procedures

The three lagoon units whose performance is described, have been operated for a number of years as integral parts of the purification methods used in Melbourne. Particular attention has been given to their operation and at times special procedures have been devised to study their performance.

The 115 East lagoon, Werribee, consists of anaerobic and aerobic units in series, with the aerobic area three times the anaerobic area. The Murteaim lagoon, Werribee, consists of an aerobic lagoon of about 550 acres preceded by anaerobic units. At first, a single anaerobic area of 34 acres was used. Later another unit of 60 acres was added; still later, a third unit of 46 acres was added. This resulted in an aerobic-anaerobic area ratio of about 5 to 1, depending on the units in operation. Both these lagoons treat settled Melbourne sewage of which a typical analysis was given in an earlier paper (2). The Braeside lagoons are essentially aerobic units treating effluent from a trickling filter plant.

The two Werribee units have been sampled twice weekly over most of their operation and the Braeside lagoon once a month. Appropriate chemical, algal, and bacteriological examinations were made on each sample. Effluent samples were taken as snap samples. Samples of the influent were usually taken as snap samples at the particular time of the day representative conditions were known to exist. When greater accuracy was wanted 24-hr composite samples were examined.

Chemical analyses were made according to "Standard Methods" (3). For reasons set out previously (2), the performance of the lagoons was calculated using the BOD of the filtered lagoon effluents. Bacteriological counts were made according to methods outlined in *The Bacteriological Examination of Water Supplies* (4). The total algal count was made according to "Standard Methods" (3) and an activity index was established. This index was arrived at by incubating the samples at room temperature for five days under ultraviolet light and determining the total count before and after exposure; the percentage increase or decrease was taken as an activity index.

115 East Lagoon, Werribee

Description

Over 98 per cent of the sewage of Melbourne (average dry weather flow,

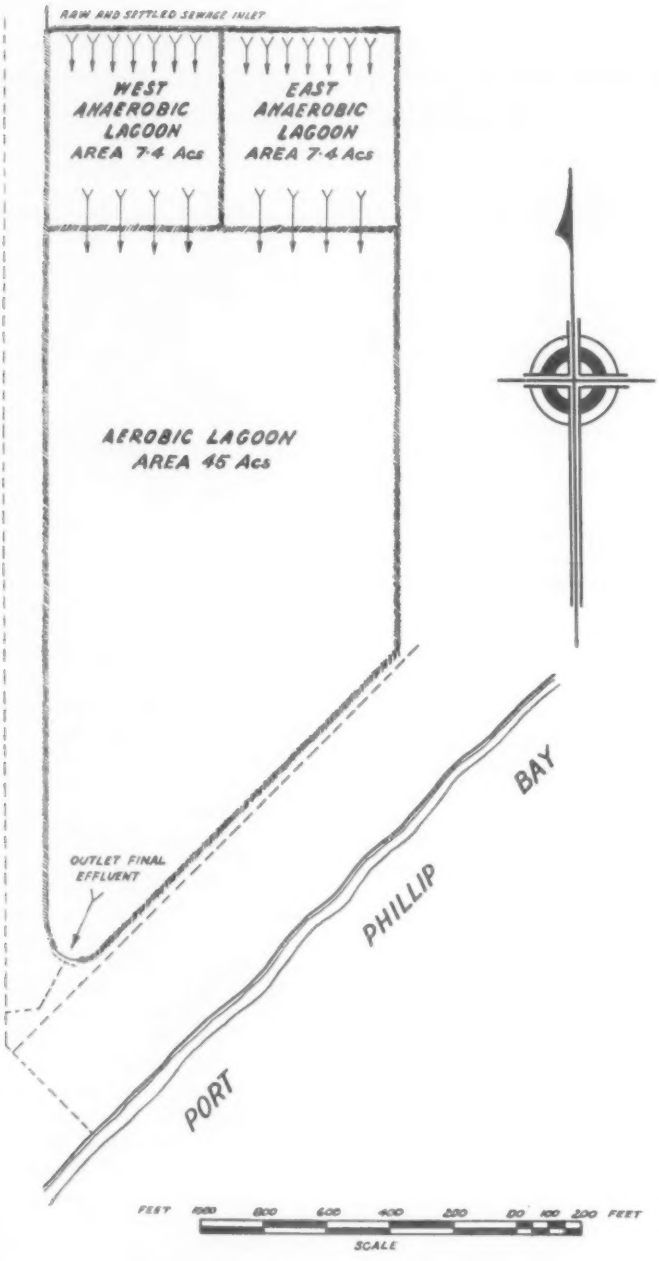
RAW AND SETTLED SEWAGE INLET
WEST ANAEROBIC LAGOON AREA 7·4 Acs
EAST ANAEROBIC LAGOON AREA 7·4 Acs
AEROBIC LAGOON AREA 45 Acs
OUTLET FINAL EFFLUENT
PHILLIP BAY
PORT
FEET 1000 800 600 400 200 0 100 200 FEET
SCALE

FIGURE 1.—Layout of 115 East lagoons.

77 mgd*) is purified by irrigation, grass filtration, and lagoon treatment at the 27,000 acre Metropolitan farm at Werribee, 24 miles from Melbourne.

The 115 East lagoon was constructed at the Metropolitan farm in 1950–51 on land of little value for the other methods of treatment practiced there. It was built to apply, on a large scale, the experimental findings reported earlier (2). The installation is shown diagrammatically in Figure 1. It consists of two 7.5-acre anaerobic lagoons in parallel and a 45-acre aerobic lagoon in series. The earlier work had shown that per unit area, very much greater BOD removals are achieved with anaerobic lagoons. Consequently, the ratio of aerobic to anaerobic area was made as small as possible, i.e., 3 to 1, to determine whether such a design would function as efficiently as the earlier experimental results suggested.

The water level was fixed at varying depths in the three ponds to suit conditions. The depth varied from 2 to 3.5 ft in the anaerobic lagoons and from 1.5 to 4 ft in the aerobic lagoon. Banks were constructed of earth and were of an average height of 4 ft, with a top width of 10 ft and 1 on 1½ side slopes. The banks were lined on the inside with 2 in. of unreinforced concrete. The invert of the raw sewage channel is above the water level and runs the full length of the north side of the anaerobic lagoons. There are seven pipe outlets to each lagoon. Anaerobic effluent discharges under scum boards and over four 4-ft long weirs along the south side of each unit and thence through pipes to the aerobic lagoon. The outlet from the aerobic lagoon consists of a 100-ft long weir discharging to an open drain.

The installation has been operated continuously since January 1951, save for brief periods when it has been desirable to cut off the flow. Flows of up to 6 mgd have been treated and several operational procedures have been examined.

Initial Operation 1951–52

Raw sewage was first admitted to the west anaerobic unit on Jan. 1, 1951, at the rate of 0.73 mgd. Sewage was admitted to the east anaerobic pond on Feb. 12, 1951. The flow was raised to between 2 to 3 mgd, averaging 2.62 mgd, between Mar. 19 and June 17, 1951. It was then reduced to 1.0 mgd, averaging 0.93 mgd, between June 17 and Oct. 21, 1951. The regulation of flow was necessary to meet a preset standard of 20 ppm BOD in the filtered effluent from the aerobic unit.

During this period the filtered BOD of the aerobic effluent exceeded 20 ppm for only one week and then it was only 21.1 ppm. It can, therefore, be claimed that the loadings used were such that a satisfactory performance was maintained throughout the initial period. The performance of the lagoon installation is summarized in Table I (a).

Owing to the variable load applied during this initial period, it was impossible to obtain much exact information about maximum capacity for purification. It will be noted, however, that even in this period, percentage removals of BOD in the aerobic lagoon were very high. When the load was 90 lb per day/acre the removal reached 73 lb per day/acre, which is similar to maximum removals previously found with aerobic lagoons.

As would be expected during the early stages of operation, the percentage removals of BOD by the anaerobic lagoon were low. An exception is noted for the period when the loading was only 32 lb per day/acre. Removals were much lower than maximum values obtained previously.

About six weeks after the commencement of operation, an intense odor arose from the anaerobic lagoons. Complaints were made by a local

* All flows are given in Imperial gallons.

TABLE I.—Performance of 115 East Lagoon, Werribee

Period	Flow (mgd)	Anaerobic Lagoon					Aerobic Lagoon					Lagoon Temp. (°F)
		BOD Load (lb/day/acre)	Infl. BOD (ppm)	Effl. BOD (ppm)	BOD Removal (lb/day/acre)	BOD Removal (%)	BOD Load (lb/day/acre)	Unfil. Effl. BOD (ppm)	Filtered Effl. BOD (ppm)	BOD Removal (lb/day/acre)	BOD Removal (%)	
(a) Performance During Initial Stage												
2/12 to 3/18/51	0.73	128	—	—	45	35	34	—	—	33	97	—
3/19 to 6/17/51	2.62	439	—	—	173	39	90	—	—	73	81	54
7/8 to 8/19/51	0.33	32	—	—	25	78	8.5	—	—	8.0	93	48
8/20 to 10/21/51	1.22	209	—	—	119	57	31	—	—	24	77	56
(b) Maximum Performance under Summer Conditions (1951–52)												
10/22 to 11/18/51	2.0	554	410	132	358	64	62	15.8	2.6	61	98	60
11/19 to 1/6/52	3.3	916	411	117	624	67	74	29.0	2.4	73	98	64
1/7 to 2/17/52	4.2	1,067	376	110	793	71	99	25.9	2.9	87	97	67
2/18 to 3/30/52	5.1	1,185	347	116	792	67	136	34.9	3.3	132	97	65
3/31 to 5/4/52	6.0	1,366	337	103	1,034	69	111	29.2	4.0	107	96	61
(c) Performance under Summer Conditions (1953, 1955, and 1957)												
1/18 to 2/14/53	5.5	1,210	316	158	604	50	191	38.9	8.6	181	94	—
2/6 to 4/10/55	2.9	630	322	101	436	67	62	24.8	2.7	60	97	—
1/10 to 3/12/57	2.0*	882	322	86	646	74	37	25.6	3.3	35	96	—
3/25 to 4/5/57	2.5*	1,883	565	97	1,560	83	54	25.3	5.9	51	94	—
(d) Performance under Winter Conditions (1952 and 1957)												
9/1 to 9/21/52	3.3	674	303	114	420	62	79	26.3	15.9	69	88	53
7/29 to 8/28/57	1.3*	520	312	180	220	42	50	19.5	7.5	48	96	—

* All raw sewage through one anaerobic unit only.

school situated one-fourth of a mile away. Associated with the odor was sufficient H_2S to cause considerable blackening of a newly painted house 300 ft from the area. The onset of odor complaints occurred about a week after the flow was increased from 0.73 to 2.62 mgd, suggesting that the anaerobic lagoon had become overloaded with solids before the deposited sludge had become fully digested. The anaerobic effluent showed 4 to 6 ppm of sulfides. The pH was 6.3 compared with the raw sewage value of 6.9. The effluent from a normally functioning anaerobic lagoon usually has a pH of 7.0 to 7.4.

Three weeks after the first occurrence of odor, the pH of the anaerobic effluent increased to 7.0 and complaints ceased. In six years of operation there has been no similar recurrence.

It must be concluded from this experience that during the start-up of anaerobic lagoons considerable attention should be given to the BOD loading of the unit and the pH of the effluent. This was watched when other anaerobic lagoons were put into operation at Werribee and no trouble was encountered.

Performance in Summer

Sludge activity in the anaerobic lagoons was developed fully by the summer of 1951–52 and the flow was gradually increased to determine how heavily a lagoon might be loaded and still produce a filtered effluent having a BOD not greater than 20 ppm. The results obtained with increasing loads are shown in Table I (b).

The maximum BOD removals under summer conditions (60 to 70°F) were 1,034 lb per day/acre for the anaerobic and 132 lb per day/acre for the aerobic lagoon. These values compare more than favorably with the expected performance deduced from the early experiments (2), i.e., 600 lb per day/acre by anaerobic and 65 lb per day/acre by aerobic lagoons.

Removal of more than 99 per cent of the BOD was achieved at these loadings, the percentage removal of that applied in each stage being remarkably constant over the 6½ months of operation. The maximum over-all BOD removal for the total area was 322 lb per day/acre or a loading of 2,230 persons per acre assuming a per capita BOD contribution of 0.14 lb per day. At this loading the calculated detention time was 1.2 days in the anaerobic and 3.7 days in the aerobic lagoon, an over-all detention of 4.9 days.

Again in the summers of 1952–53, 1954–55, and 1956–57 the lagoon performance was determined. The average values are shown in Table I (c).

The aerobic lagoon performance for 1953 is extraordinarily high and it is unlikely that it could be maintained indefinitely and still produce a filtered effluent with a BOD below 20 ppm. In fact, the BOD of the filtered effluent for the two weeks following this test period increased to 34.7 and 41.0 ppm and dropped below 20 ppm only after the flow was reduced to 3 mgd. On the other hand, the results for the early part of 1957 show an abnormally low removal which is, however, 96 per cent of the applied load. It is probable that this performance would have been substantially higher had the loading been greater.

From the six years' operation of the 115 East lagoon it would appear that the maximum BOD removal by anaerobic lagoons in summer is well in excess of 600 lb per day/acre; for aerobic lagoons it is in excess of the 65 lb per day/acre suggested from the early experiments (2) and is probably nearer 100 lb per day/acre.

Performance under Winter Conditions

During the winter of 1952 the flow to the lagoon was increased from 2.0 mgd to a maximum of 3.5 mgd, and held at that value for several weeks. Owing to heavy rains at this time, the

raw sewage was much weaker than usual but the results between Sept. 1 and Sept. 21 are typical of performance with normal sewage. These results are shown in Table I (d).

Because procedures required for other aspects of the investigation prevented the maximum flow from being applied during the other winter periods, confirmation of these figures was not possible until the winter of 1957, when the same flow was again applied. These results are also shown in Table I (d).

It will be seen that the BOD removal in the anaerobic lagoon in 1952 was 420 lb per day/acre, which is close to the experimental value of 450 lb per day/acre. The result obtained in 1957 after six years of operation, however, was much lower, being only 220 lb per day/acre. This result might be taken as a sign of some deterioration in performance with continued operation, but the value obtained the previous summer was extraordinarily high and certainly did not suggest that a drop in performance was imminent.

Quality of Aerobic Lagoon Effluent

During 38 weeks in six years of operation, the filtered aerobic lagoon effluent had a BOD exceeding 20 ppm. There were eight separate occurrences, consisting of four periods of one to two weeks during 1952 and 1953, and four longer periods, ranging from four to eleven weeks, in 1953, 1954, and 1955. The mean BOD value during these 38 weeks was 36.1 ppm and the maximum value observed was 61.1 ppm.

From a study of the periods of reduced efficiency it can be stated that with two possible exceptions poor final effluents have been caused by excessive BOD loadings on the aerobic lagoon and could have been avoided by reducing the load to a value consistent with the lagoon's capacity for purification.

One other reason for not attaining a satisfactory effluent was the excessive accumulation of solids in the aerobic lagoon, which could be prevented by suitable alteration of the anaerobic lagoon weirs.

Poor effluents may also accompany an excessive sulfide content in the anaerobic effluent. The reason for this condition is not yet clear and further work will be necessary to establish remedial measures.

While most of the periods of deteriorated performance were associated with excessive BOD loads, the question arose as to whether a satisfactory algal-laden effluent could be obtained continuously during winter months even if the BOD load was constantly maintained within the lagoon's purification capacity.

Accordingly, from July 1954, until Dec. 1956, the flow was regulated so that the BOD load on the aerobic lagoon never exceeded 60 lb per day/acre. A satisfactory filtered effluent with less than 20 ppm BOD was obtained continuously through the summer and winter of 1956 with loadings of 40 to 50 lb per day/acre, indicating that lagoons can be operated to perform efficiently throughout the year.

TABLE II.—Comparison of 1955 and 1956 Operating Data for 115 East Aerobic Lagoon

Date	Flow (mgd)	BOD Load (lb/day/acre)	Eff. BOD, Filtered (ppm)	Temp. (°F)
(a) 1955 Data				
June 12	1.0	31	25.0	51
June 19	1.0	25	21.4	50
June 26	1.0	18	41.2	49
July 3	0.5	18	26.5	48
Avg	0.9	25	28.5	50
(b) 1956 Data				
June 10	1.5	38	5.0	52
June 17	1.8	48	1.9	50
June 24	1.0	31	2.3	51
July 1	1.0	48	5.9	47
Avg	1.3	41	3.8	50

TABLE III.—Sulfide and Ammonia Content and Algal Population of 115 East Lagoon for Periods in 1955 and 1956

Date	Sulfide in Anaerobic Lagoon Effl. (ppm)	Ammonia in Aerobic Lagoon Effl. (ppm)	Total Algal Count (organisms/ml)	Activity Index*
(a) 1955 Data				
May 4	12.9	27.0	1.34×10^5	2.3
May 11	8.4	27.0	1.96×10^5	3.2
May 18	8.4	26.0	nil	nil
May 25	5.5	26.0	nil	nil
June 1	4.1	32.5	4.4×10^4	49
June 8	4.5	32.5	8.2×10^4	52
June 15	2.7	27.5	2.56×10^5	8.5
June 22	2.6	27.5	6.58×10^5	6.3
June 29	4.4	27.5	2.46×10^5	11.2
July 6	5.4	27.5	3.3×10^5	8.2
(b) 1956 Data				
May 24	3.3	32.5	12.4×10^6	0.7
May 31	2.0	32.5	7.3×10^6	1.0
June 7	3.1	32.5	7.8×10^6	0.9
June 15	2.1	32.5	5.2×10^6	0.8
June 21	2.5	32.5	2.4×10^6	1.6
June 29	3.0	32.5	2.2×10^6	1.9
July 4	4.0	32.5	—	—

* Percentage increase or decrease in total count after 5 days incubation at room temperature under ultraviolet light.

There was, however, a period of four weeks, from June 12 to July 3, 1955, when the BOD of the filtered effluent exceeded 20 ppm. In Table II performance during this period is compared with the performance during a corresponding period in 1956. Other relevant operating data also are compared in Table III. During the period in 1955 when the filtered effluent BOD exceeded 20 ppm, the BOD loading was only 25 lb per day/acre, whereas in the corresponding period in 1956 when the load was 41 lb per day/acre the filtered effluent BOD was only 3.8 ppm. The poor performance in 1955 cannot be attributed to overloading.

Regular examinations of the lagoon contents were made to determine the nature, quantity, and reproductivity of algae present. These examinations showed *Chlorella* to be predominant throughout the period of 2½ yr, with very little variation in numbers from summer to winter. The viability, or reproductivity, of the algae present was determined by exposing a sample to a fixed intensity of ultraviolet light for five days at room temperature and measuring the number of cells before and after exposure. The ratio, expressed as a percentage, was used as an activity index.

When the data in Table III are examined for comparable periods in 1955 and 1956, it will be seen that algae were absent for two weeks prior to the period of poor performance in 1955 (Table II). For the next two weeks the population was extremely low, and even for the final four weeks of the period listed the algal counts were only one-tenth of those found under normal operation in 1956. The activity index was very much higher in the period of poor performance indicating that the algal population was sub-optimal for the environment.

The toxic agent responsible for the death of the algal population would appear to be the excessive sulfide content of the anaerobic lagoon effluent over the period May 4–18, 1955. The dead algal cells in turn would impose an additional organic load on the lagoon and this, combined with the reduced efficiency due to the absence of living algae, would explain the poor performance.

Further work is now in progress to study chemical and microbiological aspects of the mechanism of the anaerobic lagoon treatment and it is hoped this will throw light on the reason for the temporary, high sulfide concentrations in the effluent.

Continuous vs. Intermittent Operation of Anaerobic Lagoon

At Werribee there are large fluctuations in the rate of raw sewage flow. Additionally, in the operation of the irrigation processes used for disposal

difficulties arise in handling the daily peak flow which arrives at the farm at night.

One very useful application of lagoon treatment is to receive these daily peak flows for 8 to 12 hr each day. It was necessary, however, to ascertain whether the performance figures obtained with uniform flow over 24 hr would apply if the sewage were added intermittently over a shorter period. In 1953 and 1955, with the total daily addition kept constant, the anaerobic lagoon was operated both continuously and intermittently. The results showed that the performance was not substantially altered by intermittent operation.

Murtcaim Lagoon, Werribee

Description

In 1936 about 570 acres of low-lying land were formed into a simple lagoon consisting of two units of irregular shape. The original purpose was to complete the purification of effluents already partially purified by irrigation processes, which would naturally drain to this area.

Following the early success with the experimental treatment of raw sewage in lagoons, it was decided to also treat settled sewage in the Murtcaim unit. It was intended by this operation to examine the large-scale performance of lagoons for the treatment of settled sewage.

The sewage admitted to this lagoon had been settled for one to two hours in flat-bottomed tanks. Settled sewage was first treated in Sept. 1947. The mode of operation of the lagoon is shown diagrammatically in Figure 2. The depth of these lagoons ranges from 3 ft to a few inches; the average depth is 21 in. Observations in 1947 showed that in the land-locked area of 34 acres (shown as Anaerobic Lagoon 3, in Figure 2) through which the sewage passed prior to entering the main area of the lagoon, sludge had deposited and the area developed into what was essentially an anaerobic unit.

The remarkable BOD removal achieved by anaerobic lagoons coupled with increasing sewage flows prompted the construction of two additional anaerobic lagoon areas. The layout of the area at this stage of development is shown diagrammatically in Figure 3.

The Murtcaim lagoons have been operated continuously for 10 yr. Several operational procedures have been tried and a vast amount of information has been obtained concerning the behavior and efficiency of large-scale sewage lagoons. Samples at the outlet and at intermediate points have been examined twice weekly throughout the 10-yr period and special samples have been collected in connection with particular points of investigation. Discussions of a number of operational aspects follow.

Purification of Partially Purified Land-treated Effluents

During the period, 1938–40, the lagoon arrangement was as shown in Figure 2. No raw or settled sewage entered the lagoon without first being substantially purified on land areas. Drainage reached the lagoon at several points and these are shown in Figure 2.

Pretreatment consisted of pasture irrigation in summer and grass filtration in winter. Detailed descriptions of these processes have been given by

TABLE IV.—Performance of the Murtcaim Lagoon after Admission of Partially Treated Sewage

Sampling Point	BOD (ppm)		Susp. Solids (ppm)		Flow (mgd)
	1946	1947	1946	1947	1947
Settled sewage	—	454	—	281	6.8
Outlet, Anaerobic Lagoon 3	—	136	—	147	—
Final effl.	12.3	14.7	78	81	—

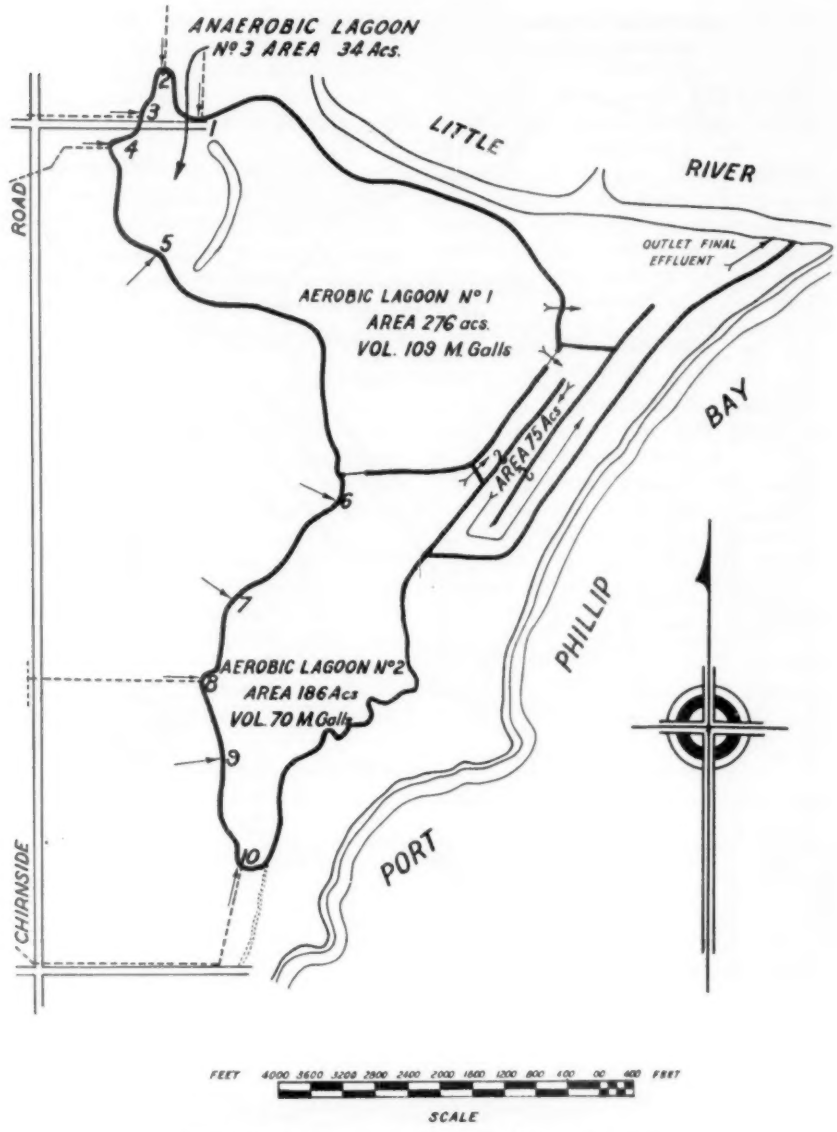

FIGURE 2.—Layout of Murtcaim lagoons in 1947.

McIntosh (5). Peak storm flows were first irrigated over rough grass areas and the night peak flows were treated in a similar way.

Over a period from Mar. to Dec. 1944, samples of most of the drainage entering the lagoon, as well as the lagoon effluent, were taken at fortnightly intervals.

The BOD loading of the lagoon was very small both in summer and in winter, 4.8 and 12.5 lb per day/acre, re-

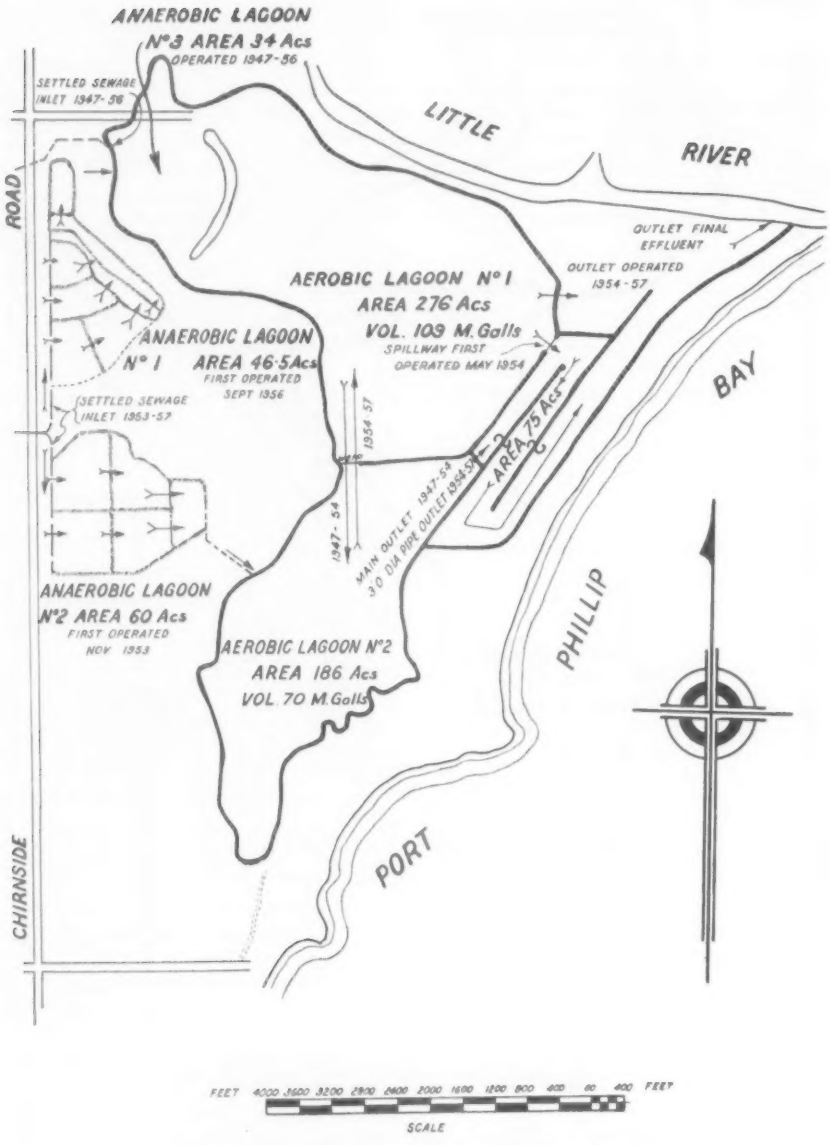

FIGURE 3.—Layout of Murtcaim lagoons in 1957.

spectively. This small loading in turn limited the performance figure to a low value. However, it was demonstrated that lagoon treatment reduced the BOD of the combined flow from 56.1 to 15.4 ppm during the summer. The winter BOD reduction was from 35.7 to 18.1 ppm. The BOD of the filtered effluent was 10.1 ppm in summer and 7.0 ppm in winter.

In summer, the drainage entering the lagoon contained 30 ppm suspended solids and the effluent contained 73 ppm. In winter, the inlet-to-outlet increase was from 25.4 to 45 ppm.

Performance under Winter and Summer Conditions

The Murtcaim lagoon first treated settled sewage in 1947 when an average flow of 6.8 mgd was added from May to Nov. In addition, the partially treated effluents described above were treated.

The average results of weekly sampling at the lagoon outlet, the outlet from Anaerobic Lagoon 3 (Figure 2), and the settled sewage inlet are shown in Table IV. Also shown are data on the 1946 effluent, when no settled sewage was treated.

These results demonstrate the ability of the lagoon to completely stabilize settled sewage in addition to the drainage effluents treated in 1946. They also indicate that most of the purification, 70 per cent on an acreage basis, occurred in the 34-acre anaerobic unit. Inspection of this area revealed that the whole of the land-locked area was acting as an anaerobic lagoon. Black sludge was continuously rising to the surface and general evidence of gas formation was observed.

In view of the ease with which the area handled this flow of 6.8 mgd attempts were made to ascertain the maximum performance of which the whole area was capable. In the summer of 1948–49 the flow to the lagoon was increased at 3- to 4-week intervals from 8.0 to 10.3, 12.1, 15.1, 17.6, and, eventually, 20.2 mgd. The flow could not be increased beyond this value because extra water was then needed to irrigate permanent pastures.

Samples were collected twice weekly and the results are shown in Table V. The BOD loading and performance of the various units at the two highest loadings are shown in Table VI.

The very low BOD of the filtered final effluent at an over-all BOD loading of 155 lb per day/acre indicates that the maximum purifying capacity of the whole lagoon had not yet been

TABLE V.—Performance of Murtcaim Lagoon under Summer Conditions

Date (1948)	Flow (mgd)	Settled Sewage		No. 3 Anaerobic Lagoon Effl.		No. 1 Aerobic Lagoon Effl.		No. 1 Aerobic Lagoon Effl. (filtered)	No. 2 Aerobic Lagoon Effl.		No. 2 Aerobic Lagoon Effl. (filtered)
		BOD (ppm)	SS (ppm)	BOD (ppm)	SS (ppm)	BOD (ppm)	SS (ppm)	BOD (ppm)	BOD (ppm)	SS (ppm)	BOD (ppm)
8/30 to 9/12	8.0	441	292	—	—	47.8	163	22.5	20.3	156	5.9
9/13 to 10/10	10.3	434	270	—	—	68.9	60	39.6	26.0	87	7.6
10/11 to 10/30	12.1	361	289	—	—	36.7	130	8.7	17.1	111	3.7
11/1 to 11/20	15.1	373	283	—	—	66.3	135	9.0	20.1	90	3.2
11/22 to 12/11	17.6	407	264	133	141	59.8	172	7.9	36.1	131	5.8
12/13 to 12/18	20.2	437	368	133	143	64.0	150	15.1	27.0	170	2.0

TABLE VI.—BOD Load and Performance of Murtcaim Lagoon during Summer of 1948

Period (1948)	Flow (mgd)	No. 3 Anaerobic		No. 1 Aerobic		No. 2 Aerobic		No. 1 + No. 2 Aerobic		No. 1 + No. 2 Aerobic + No. 3 Anaerobic	
		BOD (lb/day/acre)		BOD (lb/day/acre)		BOD (lb/day/acre)		BOD (lb/day/acre)		BOD (lb/day/acre)	
		Applied	Removed	Applied	Removed*	Applied†	Removed*	Applied	Removed*	Applied	Removed*
Nov. 22 to Dec. 13	17.6	2,106	1,417	84.8	80.0	5.4	1.4	43.4	41.6	125	124
Dec. 13 to Dec. 18	20.2	2,596	1,806	97.4	86.4	11.[illegible]	10.1	50.0	49.4	155	154

* Based on BOD of filtered effluent.
† Based on BOD of filtered influent.

reached. However, it should be pointed out the highest loading was applied for only five days and for that reason the results may not be entirely representative of performance at that flow.

The results again emphasize the extremely rapid BOD removal which occurs in anaerobic lagoons. This is strikingly demonstrated by the fact that 70 per cent of the applied BOD was removed in 34 acres of anaerobic lagoon while the remaining 30 per cent required 536 acres of aerobic lagoon. The BOD removal by the anaerobic lagoon, 1,417 to 1,806 lb per day/acre, is in excess of any result obtained with the early experimental lagoon (2). BOD removals of from 80 to 86 lb per day/acre in Aerobic Lagoon 1 compare with the results of the experimental unit. The removals in Aerobic Lagoon 2 were low because of the light loading. Over-all, the aerobic units removed BOD at the rate of 49 lb per day/acre.

During the winter of 1949 the lagoon was again loaded to capacity to determine its maximum performance under winter conditions. Over a period of 26 weeks the anaerobic unit removed 585 of the 1,142 lb per day/acre of BOD applied.

Aerobic Lagoon 1 gave a BOD removal of 54.6 lb per day/acre, which is comparable with earlier results. However, the removal in Aerobic Lagoon 2 was only 21.0 lb per day/acre because of the small loading.

Ability to Treat Weak Sewage

Over the period Mar. 8 to Mar. 11, 1949, extremely high sewage flows were received at Werribee; the daily flows being 121, 120, 112, and 83 mgd compared with an average dry weather flow of 61 mgd. The flow to the lagoon prior to the storm flow was 10 mgd and for the four days of excessive flow it was 25.4 mgd.

Beginning on Mar. 11, after the storm flow stopped, the flow to the lagoon was retained at the high figure of 23.6 mgd for 12 days. During this period the sewage was of normal strength in contrast to the weak sewage handled during flood conditions.

To examine the performance under these abnormal conditions, samples of settled sewage and the effluent from the anaerobic unit were taken at 2-hr intervals and 24-hr composites prepared from them. Samples of the effluent from Aerobic Lagoons 1 and 2 were taken as daily snap samples.

The results show that high flows of weak sewage can be adequately treated by the Murteaim units. During the period Mar. 8 to Mar. 11, 1949, the BOD of the filtered effluent from Aerobic Lagoon 1 was only 5.5 ppm.

The BOD removal of the anaerobic lagoon, 1,260 lb per day/acre, was again extraordinarily high, being comparable to previous values obtained when treating normal strength sewage. Over 70 per cent of the BOD load was removed in the anaerobic area and 27 per cent was removed in the two aerobic lagoons. The over-all BOD removal in the aerobic units was 51 lb per day/acre.

Recently, storm flows of up to 35 mgd have been treated successfully. During this period the BOD of the filtered final effluent did not exceed 5 ppm. As the channel capacity does not permit flows greater than 35 mgd, purification capacity of flows greater than that has not been determined.

During the 12-day period that followed the storm flows of Mar. 1949, the BOD of the filtered final effluent exceeded 20 ppm on only three days. This BOD reduction compares to the maximum performance recorded with dry weather flows shown in Table VI.

Multi-purpose Function

Except for periods of experimentation, the Murtcaim installation has functioned since 1947 as an integral part of the method used for the treatment of Melbourne's sewage.

During dry weather, the major part of the sewage received at Werribee is treated by intermittent irrigation on 12,000 acres of pastures in summer, and continuous discharge over 3,400 acres of grass filtration area in winter.

At times of prolonged heavy rain and high sewage flows, the volume irrigated on pastures frequently has to be restricted; consequently, large volumes of sewage have to be treated by other means. Up to 35 mgd of the flow, at such times, has been treated in lagoons as described earlier. Similarly in winter, loadings to the grass filtration areas are adjusted to their appropriate capacity and the excess is sent to the lagoons.

As explained earlier, the daily peak flow arrives at night, and to avoid employing extra gangs of men at overtime rates the flows are discharged to the lagoon over a 8- to 12-hr period each day.

TABLE VII.—Settled Sewage Treated in Murtcaim Lagoons, 1947–1956

Year	Annual Flow (mil gal)	Daily Flow (mgd)
1947	290	0.8
1948	2,259	6.2
1949	4,653	12.7
1950	3,099	8.5
1951	3,071	8.4
1952	3,367	9.2
1953	4,692	12.9
1954	4,881	13.4
1955	4,527	12.4
1956	4,620	12.6
Total	35,459	

To indicate the increasing importance of the lagoon in treating sewage at Werribee, the flows that have been treated each year are listed in Table VII. The mean daily flow now being treated by this lagoon is 12.6 mgd.

The average BOD of the unfiltered final effluent over the period 1947–57 has been 24.5 ppm, and that of the filtered effluent, 7.4 ppm. Except for periods when experimental procedures were being tried, the BOD of the filtered final effluent has exceeded 20 ppm for only 15 weeks in 10 years of operation.

Comparison of Murtcaim and 115 East Lagoons

The differences in design between the Murtcaim and 115 East lagoons make it pertinent to compare the performance of the two installations to discover which is more efficient.

The Murtcaim Anaerobic Lagoon 1 has been in operation only since Sept. 1, 1956, and it is too soon to examine the results from it. However, Anaerobic Lagoon 2 has been used since Nov. 30, 1953, and the following is a summary of its behavior.

TABLE VIII.—Load and Performance of Anaerobic Lagoon 2, Murtcaim

Date	Flow (mgd)	BOD (ppm)		BOD (lb/day/acre)		BOD Removal (%)	Calc. Detention (days)
		Infl.*	Eff.	Applied	Removed		
(a) Summer Operation							
11/7 to 12/19/54	7.8	355	48	461	399	87	2.9
1/1 to 4/3/56	15.7	307	86	803	578	72	1.4
4/10 to 5/8/56	8.1	411	126	555	398	72	2.8
(b) Winter Operation							
6/27 to 8/22/54	6.0	400	119	400	281	70	3.7
7/31 to 9/25/55	9.5	228	81	361	233	65	2.4
6/17 to 7/29/56	5.9	214	114	210	100	48	3.8
8/1 to 8/27/57	12.0	418	220	836	396	47	1.9

* Settled sewage.

The layout of these particular ponds is shown in Figure 3. Because of the odor problem encountered with the start-up of the anaerobic areas at 115 East lagoon, the Murtcaim anaerobic ponds were loaded very lightly over the early stages. A flow of 0.5 mgd was admitted for the first 10 weeks. Then the flow was increased gradually to 3.0 mgd after 17 weeks; and to 6.0 mgd after 31 weeks. Odor troubles were avoided entirely. The pH of the ponds was above 6.8 throughout the start-up period.

Although this anaerobic lagoon was not loaded to capacity at any time, large flows have been handled. Typical results for summer and winter operation are shown in Table VIII.

The summer BOD removals shown are all lower than the experimental value of 600 lb per day/acre. However, the load was quite small for all three periods. It is believed that if the load had been greater the performance would have approximated the experimental value more closely. Even so, it is likely that the maximum performance of this unit would have fallen short of the very high values obtained at the 115 East lagoon. Winter performance figures also fall short of the experimental value. Once again, the small load is believed to cause the lower BOD removal.

With anaerobic units in series, it is to be expected that considerable time will elapse before the accumulation of active, digesting sludge is sufficient to permit maximum purifying capacity. Assuming sludge accumulation to be a significant factor, ultimate capacity would be achieved only after a considerable period. From the results obtained at both installations it would appear that anaerobic lagoons designed as a number of ponds in series attain maximum capacity more slowly than when the unit consists of a single pond or a number of ponds in parallel.

Sludge Accumulation

Over a period of 10 yr the Murtcaim installation has treated 35,459 mil gal of settled sewage without any necessity for sludge removal. However, in the summer of 1956–57, Aerobic Lagoon 1 and Anaerobic Lagoon 3 were taken out of operation, drained, and the surface allowed to dry. Inspection revealed that in Anaerobic Lagoon 3, which had been out of service since June 17, 1956, the sludge layer was only 3 to 6 in. thick. Apparently most

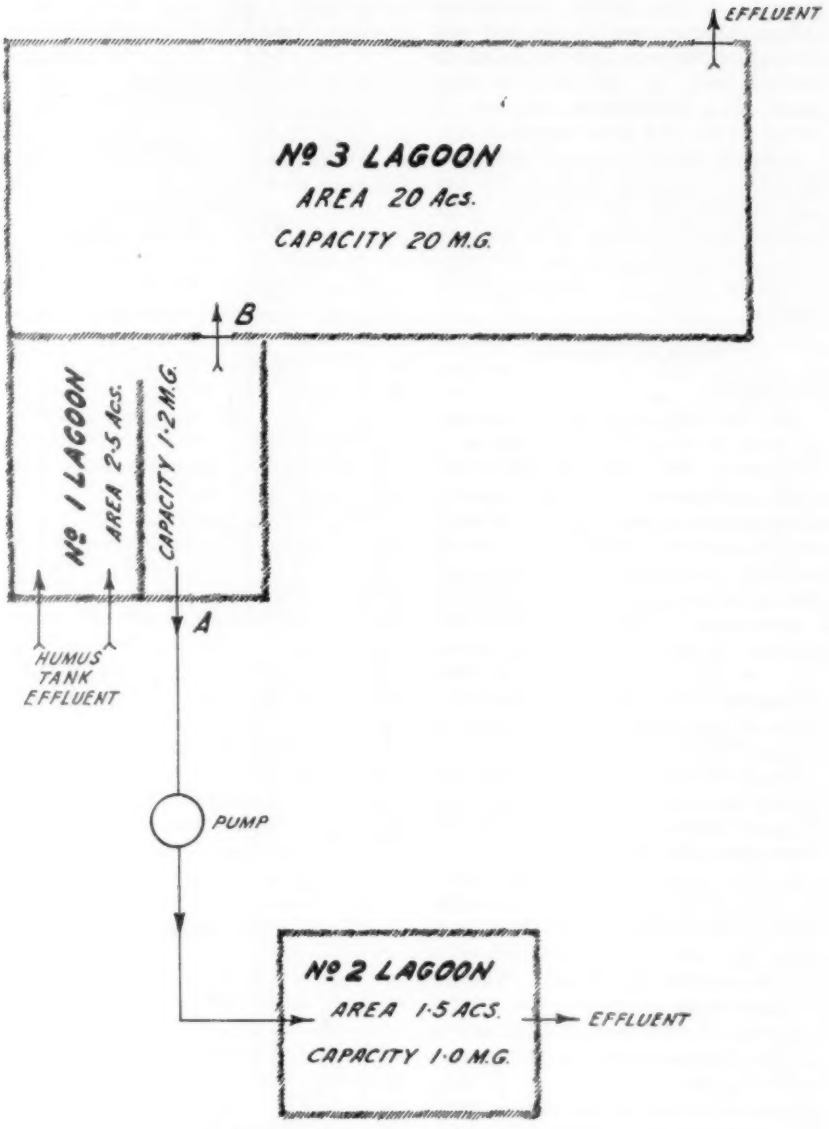

FIGURE 4.—Layout of Braeside lagoons.

of the solids had moved into Aerobic Lagoon 1. Over 80 per cent of the area of Aerobic Lagoon 1 there was only about 2 to 3 in. of sludge. Over the remaining 20 per cent, however, the sludge banks were 18 to 24 in. thick. The thicker deposits were mostly near the present outlet weir.

Although this sludge accumulation did not materially alter the volumetric

capacity of the lagoon, observations during summer months showed that gassing of the accumulated solids interfered with the efficiency of treatment. This phenomenon was also observed at the 115 East lagoon.

It would appear that with long-term operation of aerobic lagoons, the passage of solids from the anaerobic to the aerobic areas interferes with performance. This means, of course, that steps should be taken to prevent such a transfer.

Braeside Lagoons

Description

The Braeside plant treats the sewage from an area 16 miles southeast of Melbourne. The plant consists of primary sedimentation with separate sludge digestion, two trickling filters in parallel, and two humus tanks, also in parallel. In summer, the humus tank effluent, after passing through Lagoon 1, is pumped to Lagoon 2. The effluent from Lagoon 2 is used for irrigation. In winter, the humus tank effluent passes from Lagoon 1 to Lagoon 3 prior to discharge. The layout is shown in Figure 4.

The treatment plant was first operated in 1941. At present the contributory population is 24,000 and the dry weather flow is 1.2 mgd.

At the commencement of operation, the filter loading was such that the BOD of the humus tank effluent was quite low and the lagoons did little more than polish the effluent. With increasing flows, however, the humus tank effluent has deteriorated and a greatly increased load has been placed on the lagoons.

Lagoons 2 and 3 always contain some DO. At the highest loadings Lagoon 1 has been deficient in DO but there have been no appreciable odors.

Performance

The performance of the plant is examined monthly. Samples are collected over a 24-hr period at various

TABLE IX.—Performance of Braeside Lagoons

Year	Season	Flow (mgd)	Humus Tank Effl.		Lagoon No. 1				Lagoon No. 2*				Lagoon No. 3†			
			BOD (ppm)	SS (ppm)	Effl. BOD (ppm)	Effl. SS (ppm)	BOD‡ Load (lb/day/acre)	BOD Removal (lb/day/acre)	Effl. BOD (ppm)	Effl. SS (ppm)	BOD Load (lb/day/acre)	BOD Removal (lb/day/acre)	Effl. BOD (ppm)	Effl. SS (ppm)	BOD Load (lb/day/acre)	BOD Removal (lb/day/acre)
1942–43	Summer	0.3	30	38	12	27	34	20	16	49	24	−7	—	—	—	—
	Winter	0.3	33	38	7	26	73	57	—	—	—	—	10	79	1.1	−0.4
1947–48	Summer	0.5	30	43	10	17	59	40	8	17	31	6	—	—	—	—
	Winter	0.5	29	46	6	9	110	87	—	—	—	—	3	60	1.8	0.7
1951–52	Summer	0.75	38	61	19	31	113	54	15	21	97	25	—	—	—	—
	Winter	0.75	42	59	16	26	240	149	—	—	—	—	4	36	5.9	4.4
1955–56	Summer	1.0	51	75	36	72	203	59	30	20	241	49	—	—	—	—
	Winter	1.0	54	71	19	28	415	267	—	—	—	—	4	29	9.7	7.5

* Operated in summer only. † Operated in winter only. ‡ Effective area: summer, 2.5 acres; winter, 1.3 acres.

points in the plant and a single grab sample is taken of the various lagoon effluents.

The performance of the three lagoons, averaged over 12 monthly periods for the years 1942–43, 1947–48, 1951–52, and 1955–56, are shown in Table IX. The BOD data reported are for unfiltered samples.

The BOD loadings on Lagoon 1 have been extremely high, up to 415 lb per day/acre in winter and 203 lb per day/acre in summer. The performance in summer has been very much lower than in winter. In 1955–56 the BOD removal was 58.8 lb per day/acre in summer, compared with 267 lb per day/acre in winter. From experience with other lagoons, the summer removals are as high as might be expected, but the winter performance is far in excess of any of the results obtained at Werribee.

There was very little algal matter present in the lagoon as shown by the low suspended solids content of the effluent. There were, however, considerable quantities of solids carried over from the humus tanks and it is possible that their rate of digestion in the lagoon is much greater in summer than winter. Rapid digestion during the summer could possibly place an increased oxygen demand on the pond. Moreover, an oxygen demand of this type would go undetected because of sampling procedures used.

The suspended solids in the effluents from all three lagoons were quite low on nearly all occasions. This suggests that for most of the period of operation there has been very little algal development. This has been confirmed by visual observation. A lagoon at Castlemaine, Victoria, which treats the effluent from a trickling filter plant, also has been found to produce an algal-free effluent. The reason for the absence of a profuse algal development in these lagoons is not clear. The effluent at all times contained some oxidized nitrogen in contrast to the Werribee effluent which contained none, suggesting that this might be responsible for the non-development of algae.

Discussion

General

The 16-yr study of Melbourne's lagoons has shown that the process may be relied on to give satisfactory treatment when used for four different purposes: (a) to complete the treatment of trickling filter effluents; (b) to complete the treatment of land-treatment effluents; (c) to give complete treatment to normal strength sewage; and (d) to give complete treatment to weak, storm-flow sewage.

Braeside Lagoons

The lagoons at the Braeside treatment plant have been subjected to an ever-increasing load. Their ability to produce continuously a satisfactory final effluent has demonstrated the valuable function lagoons can serve in connection with overloaded trickling filter plants.

The absence of profuse algal growths in these lagoons was of considerable interest. Experience in other parts of Victoria would suggest that algae seldom develop in lagoons treating trickling filter effluents. The BOD removal by relatively algal-free lagoons would have been expected to be small inasmuch as experience at Werribee suggests a maximum removal of 25 to 30 lb per day/acre. However, the actual removals achieved by Lagoon 1, 55 to 60 lb per day/acre in summer and the extraordinarily high figure of 267 lb per day/acre in winter, are far in excess of the Werribee values. These high performance figures and the anomalous higher value in winter demonstrate the desirability of further study of this hitherto unexplored application of lagoon treatment.

The experience at the Braeside treatment works suggests that economical complete treatment may be effected by using the high-rate trickling filter and

lagoon processes in combination. At Braeside, the complete treatment of an essentially domestic sewage from a population of 24,000 is achieved by trickling filters containing 800 cu yd of stone, followed by 20 acres of lagoons.

Murtcaim Lagoon

The early operation of the Murtcaim lagoon, Werribee, demonstrated the ability of lagoons to complete the treatment of partially treated land effluents. Treatment of sewage by the land processes of pasture irrigation in summer and grass filtration in winter normally results in a high-class fully-treated effluent. When weather conditions are unsuitable, however, there is some deterioration in performance. In these instances lagoons are used to great advantage.

The treatment of large volumes of weak sewage under storm-flow conditions is a particularly difficult problem at Werribee. This problem will become more acute when a new 250-mgd pumping station goes into operation. Present pumping capacity is 130 mgd. Earlier experimental work has shown that such weak sewage (BOD of 150 to 200 ppm) may be treated by holding it in ponds for 20 to 30 days. Under these conditions the BOD removal is of the order of 50 to 60 lb per day/acre. At present there is under construction a lagoon area of 2,000 acres to handle the expected storm flows in this way. However, the results of treating weak sewage by continuous treatment in two-stage lagoons suggest that more efficient use of the area would be made if it is operated on a continuous-flow basis.

The results of operation of large-scale, anaerobic-aerobic lagoons to treat normal strength sewage have confirmed the performance data obtained in the earlier studies (2). Maximum summertime BOD removals of an anaerobic lagoon ranged from 578 to 1,806 lb per day/acre, which are in excess of the value of 600 lb per day/acre obtained in the experimental work (2). Winter removals ranged from 420 to 540 lb per day/acre, which are very close to the experimental value of 450 lb per day/acre (2). As BOD removal in the anaerobic units is 60 to 70 per cent, conservative BOD design loadings would be, say, 900 to 1,200 lb per day/acre in summer, and 675 lb per day/acre in winter.

Many investigators have reported BOD removals by aerobic lagoons to be of the order of 50 to 70 lb per day/acre. The results at Werribee have been of the same order although summer removals have been somewhat higher. Design figures of 60 lb per day/acre in winter and 90 to 100 lb per day/acre in summer would be reasonable values to adopt.

Aerobic-Anaerobic Ratio

The ratio between the area of aerobic and anaerobic units is an important design factor. The early experiments utilized a ratio of 15 to 1 (2). The Murtcaim lagoon, before the construction of Anaerobic Lagoons 1 and 2, also had a ratio of about 15 to 1. The 115 East lagoon was deliberately designed with the very low ratio of 3 to 1 in order to examine the practicability of such a design. The Murtcaim lagoon, including the areas of Anaerobic Lagoons 1 and 2, has a ratio of 5 to 1.

The 115 East lagoon, with the low ratio of 3 to 1, proved a bit sensitive to short-term changes in the BOD of the anaerobic effluent, whereas the stability of performance at a ratio of 15 to 1 suggests that this ratio is unduly conservative. The data indicate ratios between 5 to 1 and 10 to 1 should prove adequate. Based on past performance, an optimum area ratio of 6.0, and a lagoon depth of 2 ft, the required detentions for Melbourne sewage in summer are 1.25 days in the anaerobic and 7.5 days in the aerobic units. In winter, the detentions are 4.75 and 28

days for the anaerobic and aerobic units, respectively.

Poor Performances

Particular attention has been paid to periods of poor performance in order to understand the reason for their occurrence. In most cases, excessive BOD loading was believed to be responsible for the upsets. Other conditions believed to contribute to poor performances include the development of localized septic areas associated with sludge banks in the aerobic lagoons and, very occasionally, high sulfide concentrations in the effluent from the anaerobic units.

Sludge Banks

The development of sludge banks in the aerobic lagoon is caused by the carry-over of solids from the anaerobic unit. The interposition of short-time sedimentation units between the two lagoons should greatly minimize this problem. The construction of the anaerobic lagoon as a series of ponds would also impede the discharge of solids to the aerobic unit.

The frequency of sludge removal from lagoons has considerable bearing on the cost of operation. The frequency will depend to a great extent on the solids content of the sewage being treated and the loading intensity. Experience here indicates that both anaerobic and aerobic lagoons require desludging only every 6 to 10 yr. Where loadings are lighter, sludge removal would, of course, be less frequent.

Odors

Owing to the strength of the sewage to be treated, it has been found impossible to maintain aerobic conditions in a single-stage lagoon unless very generous detention is provided. This was demonstrated by the rapid development of anaerobic conditions in the part of the Murtcaim lagoon adjacent to the inlet.

With the two-stage anaerobic-aerobic process, devised to treat strong sewage, the aerobic section remains odor-free without any special attention. There is, however, a certain amount of odor detectable, at times, from the anaerobic units. Provided such units are properly operated, the sulfide content under Melbourne conditions has been found to be 2 to 4 ppm. Since the pH of the lagoon contents is higher than that of raw sewage, the odor level is below that associated with a similar area of raw sewage. Extreme odor nuisance may arise at the commencement of operation of new units through incorrect loading. This can be prevented by careful supervision of the admitted flow. Nevertheless, it should be recognized that a certain amount of odor normally is present and for that reason an aerobic-anaerobic installation should not be placed immediately adjacent to built-up areas.

Depth

The depth of aerobic lagoons described herein varies between 1.5 and 4 to 5 ft. Conditions of topography have been permitted to govern the depth and, as shown in the earlier experiments (2), this variation has very little influence on performance. Anaerobic lagoons, of course, must be deep enough to provide adequate sludge storage capacity. The depth of those units should be not less than 3 to 4 ft.

Conclusion

Over periods of 6, 10, and 16 yr, respectively, three lagoon installations have been studied. These lengthy trials offer rather conclusive proof of the reliability of this type of treatment. Repeated checks on performance indicate that the performance results reported herein may be reproduced continuously. Apart from sludge removal at very infrequent intervals, very little maintenance is necessary.

Acknowledgments

The authors wish to thank Mr. A. F. Ronalds, Engineer-in-Chief, Melbourne and Metropolitan Board of Works, for permission to publish this paper, and Mr. J. A. McIntosh, Chief Investigation and Design Engineer, for his interest in the work. Our thanks are also due to members of the laboratory staff for assistance with the analytical work. Especially are we indebted to Miss E. M. Jackson for the algological examinations, and to Mr. S. S. Searle, Farm Manager, and Mr. C. F. Kirby, Resident Engineer, for supervision of field procedures during experimental operation of the Werribee lagoons.

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NTTCIW MEETS IN CINCINNATI

The National Technical Task Committee on Industrial Wastes held its ninth annual meeting December 11–12 at the Robert A. Taft Sanitary Engineering Center in Cincinnati, with 52 scientists and engineers representing many of the nation's industries in attendance.

The Task Committee, chaired by Dr. Richard D. Hoak, Senior Fellow of the Mellon Institute, Pittsburgh, continued to direct its attention both to immediate and long range planning concerning problems related to industrial wastes. The Committee was created in 1950 by the Surgeon General of the U. S. Public Health Service. It serves as an industry forum on waste problems and as an advisory group to the Public Health Service.

At the technical session the four task groups of the Committee (food industries, mineral products, chemical processing, and general industry) met in separate sessions to exchange and consolidate their views on their specialized problems. Summaries of these meetings were then reported to the entire group.

During the business meeting the following were elected officers for the coming year: Ray S. Glynn, Director of Sanitation Research and Development, Association of American Railroads, *Chairman;* A. J. Steffen, Director of Sanitary Engineering, Research and Technical Division, Wilson & Co., Inc., Chicago, *Vice Chairman;* L. S. Warrick, Sanitary Engineer Director, Technical Services Consultant, Water Supply and Water Pollution Control Program, Public Health Service, *Secretary.*

CLOGGING STUDIES OF FINE BUBBLE DIFFUSER MEDIA*

By Philip F. Morgan

Professor of Sanitary Engineering, State University of Iowa, Iowa City, Iowa

Fine bubble diffusion of air into sewage has been generally used as the most economical method of supplying dissolved oxygen for aerobic sewage treatment systems since the development of the activated sludge process. The fine bubbles are desirable since they provide added total liquid-gas interfacial area for oxygen transfer and smaller bubbles rise through the liquid more slowly, thereby providing a longer contact time with the liquid.

For many years the importance of fine bubble diffusion was generally accepted but it was only in recent years that investigators have attempted a thorough study of the actual rates of oxygen transfer from bubbles to the surrounding liquid. These studies have been reported by Ippen and Carver (1), Carver (2), King (3), Haney (4), and Pasveer (5).

In spite of this progress fine bubble diffusion has not always been successful because of the problem of clogged diffuser media. At some plants clogging has been so bad that fine bubble diffusion has been abandoned, yet at others no serious difficulty has been encountered.

A study of the causes of clogging at those plants where the problem has been encountered has led to conflicting results. At some the cause was apparent and remedial measures were effective while at others the cause was not apparent. In an attempt to better understand the various causes of diffuser media clogging, a laboratory study of the problem was undertaken in 1945 and is summarized in this paper. Other details of the study have been presented elsewhere (6).

Various causes of clogging, both external and internal, were investigated including the effect of iron salts, calcium bicarbonate hardness, fine sand in the liquid, and the effect of particulate matter and humidity in the air supply.

Synthetic Plant Conditions

These studies were undertaken to reproduce clogging in the laboratory similar to that encountered in operating plants but under controlled conditions where quantitative data could be obtained. All of these laboratory studies can be classed as accelerated studies because the work was planned to clog the diffuser media in as short a time as possible and yet to be comparable to plant conditions. In most cases the laboratory conditions are comparable to the worst possible field conditions.

Each laboratory clogging study was carried on with 3 1-ft long diffuser tubes mounted along one side of an aeration tank having a width of 5½ ft, a water depth of 4 ft, and a length of 2½ ft. The bottom and top edges of the tank were filleted to enhance the rolling action similar to that in conventional diffused-air aeration tanks. Air was supplied by a 12-cfm rotary, positive-displacement blower, and was metered by an orifice to each diffuser tube. The quality of the air was controlled by the use of line-filters and the quantity was determined by dis-

* Presented at the 13th Industrial Waste Conference, Purdue University; Lafayette, Ind.; May 5–7, 1958.

charging a known volume of air through a Soxhlet thimble according to the procedure suggested by Beck (7).

Once a test was started, operation was continuous to the end of the test period. Air rates and all pressure readings were recorded once a day and air flow to the individual tubes was adjusted as necessary to maintain a constant flow of 3 cfm per 1-ft tube.

Iron Clogging

The primary object of this series of studies was to determine the effect of a ferrous salt in the aerating liquor on the rate of tube clogging.

For Runs 2 and 3, there was a continuous flow of sewage through the tank to provide a detention period of about 1½ hr. Ferrous sulfate was added to this flow to provide an average concentration of approximately 100 ppm Fe in the incoming sewage. To provide a control, an additional tank was utilized. This tank received a similar flow of sewage but did not receive iron salt. The diffuser units for these two runs were standard saran cord, wrapped stainless steel core tubes.

In Run No. 2 the effect of high particulate matter in combination with iron was observed by filtering the air to only one diffuser. The average quality of the raw air was 4.7 mg of particulate matter per 1,000 cu ft of raw air on the basis of a 60,000 cu ft sample. The results of the run are shown in Figure 1. It is apparent that the iron was responsible for an exceedingly rapid rate of clogging and, at this rate of clogging, the high particulate matter had no appreciable effect. It is also apparent that this was caused by the iron salts and not the sewage since the control showed no increase in head loss.

Run No. 3 was conducted in exactly the same way as the earlier run except that head loss data were recorded at greater frequency and were compared with the actual hours during which the iron was added. The iron added over each 24-hr period provided an average of 100 ppm as iron in the incoming sewage but the period of actual addition was somewhat less than 24 hr. The period of iron addition as well as

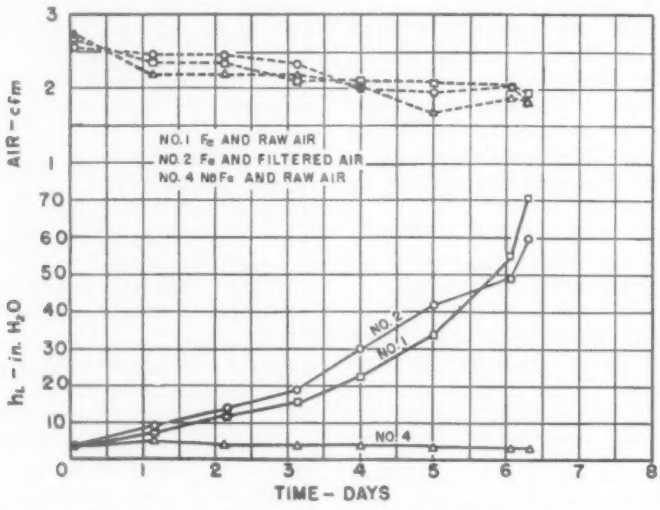

FIGURE 1.—Effect of ferrous iron salts on diffuser clogging rate.

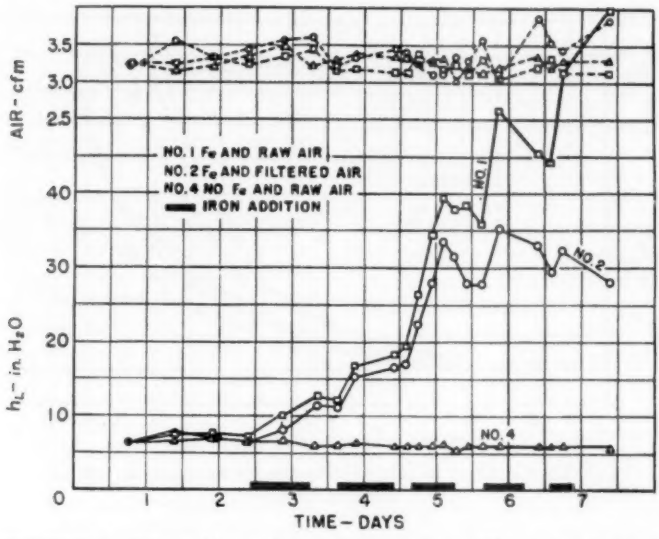

FIGURE 2.—Effect of intermittent ferrous iron on diffuser clogging rate.

head loss results are shown in Figure 2. Cleaned, rather than new, diffuser units were used for this series but this apparently had little effect. The raw air had an average particulate content of 5.0 mg/1,000 cu ft and the filtered air had 0.0 mg/1,000 cu ft on the basis of two 23,000-cu ft samples. The iron addition was not started until 2½ days after head loss observations were begun. When the iron was started its effect was immediately apparent and each time it was temporarily stopped there was a partial recovery. It would also appear that the particulate matter in the raw air aggravates the clogging as indicated by the difference in head loss between No. 1 and No. 2 tubes even though it had no effect in this short period on the control.

Calcium Bicarbonate Clogging

Since natural hardness in water has also been cited as cause for diffuser media clogging, this series of studies was undertaken to determine at what rate clogging could be accomplished under laboratory conditions. Hard water was artificially produced in two tanks which were identical to the aeration tank by diffusing CO_2 through a high-calcium lime suspension according to the formula

$$3Ca(OH)_2 + 6\,CO_2 \rightarrow 3Ca(HCO_3)_2.$$

Each day one tank was charged with water, lime, and CO_2, then allowed to stand quiescent for about 23 hr to allow for the precipitation of excess $CaCO_3$. The clarified hard water was pumped to the aeration tank at a rate of 0.15 to 0.25 gpm until the following day, when the other tank of hard water would be ready to use. The aeration tanks thus received a continuous flow of water containing about 650 ppm calcium bicarbonate hardness. The natural alkalinity of water used for making this hard water was 100 to 175 ppm.

Runs 6 and 7 were completed to determine the rate of clogging of saran-wrapped diffuser tubes with hard water, using both clean and dirty air. The results are shown in Figure 3. It is apparent that the tubes were im-

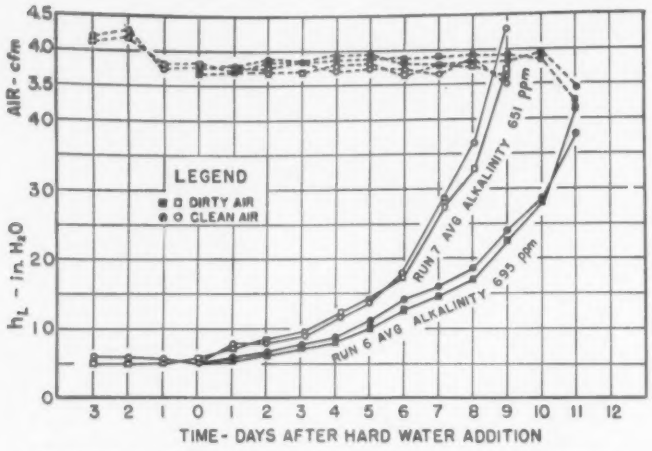

FIGURE 3.—Effect of calcium bicarbonate hardness on diffuser clogging rate.

mediately affected by the hard water and that the particulate content of the air had no effect on the clogging rate for the first 11 days of the study. However, in Run 6 after 17 days (not shown in Figure 3), the dirty air did result in additional clogging even though it contained only 0.8 mg/1,000 cu ft. Run 7 was not continued beyond the time shown in Figure 3 to determine possible additional effect of particulate matter on the clogging rate.

In considering these results in relation to natural hardness it must be remembered that this hardness was all calcium bicarbonate. A similar effect would not be expected with magnesium bicarbonate hardness because of its greater solubility.

Sand Clogging

In an attempt to clog diffuser media with fine sand, a supply of silica sand having the analyses shown in Table I was added directly to the aeration tank. The tank was initially filled with tap water and daily additions made up for evaporation. The sand was maintained in suspension by the circulating current in the aeration tank and by two air lifts which continuously lifted the sand deposited below the tubes.

Figure 4 presents the data from Runs 11C and 11D. It indicates the rate of increase of head loss of three media in the presence of sand and the average concentration of sand suspension for the duration of each tube test. The air supply for both of these runs was filtered, and for Run 11D the average particulate content was 0.034 mg/1,000 cu ft. Quantitative data on the air quality are not available for Run 11C. It is apparent that all three media, saran, ceramic, and polyethylene, were clogged by the sand and that the saran was clogged somewhat sooner.

On the basis of the clogging rate of three saran tubes, the concentration

TABLE I.—Analysis of Sand Used in Diffuser Clogging Experiments

Grain Size (μ)	As Added to Aeration Tank (per cent)	As Suspended in Aeration Tank (per cent)	Material Removed from Clogged Tube	
			As Collected (per cent)	Soluble in HCl (per cent)
Over 250	0.0	0.0	7.4	15.9
250–147	0.3	0.1	7.2	22.7
147–105	26.3	34.8	22.8	10.2
105–74	51.9	47.5	27.2	5.9
Less than 74	21.5	17.6	35.4	7.0

of the sand in the range tested appeared not to control the rate of clogging since the tube in the lowest average concentration of 658 ppm clogged at about the same rate as the tube in the highest concentration of 992 ppm.

An analysis of the sand removed from the windings of a clogged saran tube (Table I) indicated that some of the particles were considerably larger than the original sand and further that these particles were partly soluble in HCl. Microscopic examination of these larger particles confirmed the fact that they were mostly clumps of the smaller silica sand particles cemented together, presumably with calcium carbonate. This would indicate that, at least for these tests, the sand clogging may actually have been a combination of sand clogging and calcium carbonate deposition. Since the greatest proportion of the silica material removed from the windings, after correcting for the cemented particles, was under 74 μ, it can be assumed that it is the fine sand that causes the clogging. This may explain why sand clogging is seldom encountered in plants in view of the fact that sand particle sizes this small are rarely present.

Effect of Humidity

The effect of humidity in the air on the rate of diffuser media clogging, in combination with each of the other causes of clogging, was investigated as part of other studies. To check the effect of humidity one tube in a study received air to which steam was added. The relative humidity of the air before humidification was determined daily, and the amount of moisture needed for 100-per cent saturation at the temperature and pressure conditions inside the diffuser tube was determined and was added as wet steam just inside the diffuser tube.

The effect of humidification of the air supply on the rate of clogging under two operating conditions is shown in Figures 5 and 6. A summary of results from five runs in which humidification was used is presented in Table II. From an examination of the curves and the Table, it appears that humidification very materially increases the clogging rate when appreciable amounts of particulate matter are present in the air supply. It materially increases the clogging caused by ferrous iron in sewage, even with air that until recently was considered relatively clean. Humidification has

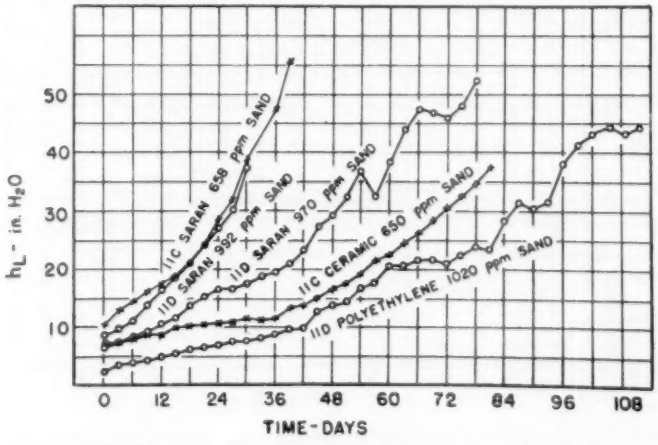

FIGURE 4.—Effect of fine sand on diffuser clogging rate.

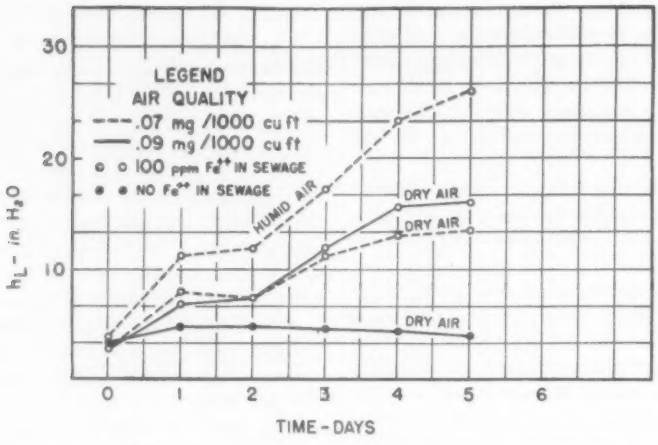

FIGURE 5.—Effect of humidity on diffuser clogging rate with 100 ppm ferrous iron in sewage.

no effect when a truly clean air supply is used.

It can, therefore, be concluded that humidification is not generally of value in reducing clogging and, in fact, when the air supply contains particulate matter and when ferrous iron is present in the sewage, it is definitely harmful. This generally corroborates plant experience where head loss has been observed to increase suddenly during warm humid weather. The possible value of humidification where the air supply is clean and high calcium bicarbonate hardness is encountered is being investigated.

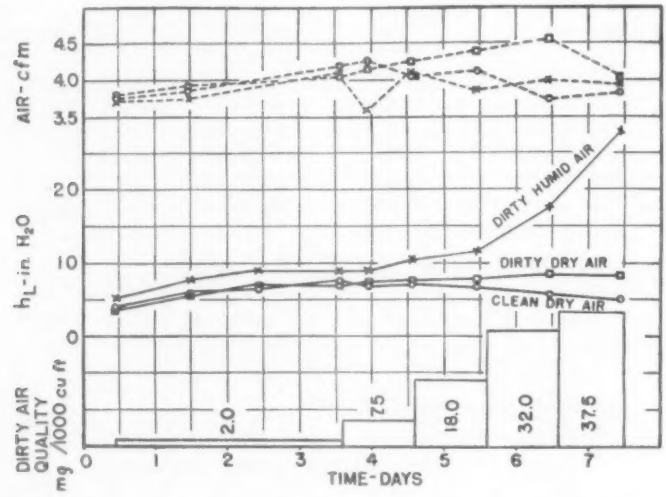

FIGURE 6.—Effect of humidity on diffuser clogging rate with particulate matter in air supply.

TABLE II.—Effect of High-Humidity Air on Rate of Clogging Diffuser Media in Sewage

Run No.	Clogging Material	Air Humidity	Air Quality (mg/1,000 cu ft)	Clogging Rate
1	Fe^{++}	Partial	0.07	Double that at same quality dry air
2	Fe^{++}	Partial	0.0	No effect
3	Fe^{++}	100%	0.0	No effect
4	Particulate matter	100%	Dirty*	Three times that of same quantity dry air
5	Particulate matter	100%	1.8 to 43.3	Several times that of same quality dry air

* Quantitative data not available.

Effect of Particulate Matter on the Air Supply

Particulate matter in the air supply is probably the most common cause of clogging and yet this is the most difficult to reproduce in the laboratory because of the difficulty of controlling the addition of these solids. Various dust-feeding devices such as those recommended by the American Air Filter Institute (8) were considered but were rejected because they could not be adapted to the conditions required for testing diffusers nor could they be operated at a low enough rate of dust feed to be comparable to field conditions. The particulate feeder finally selected was a common kerosene lamp set at a blower intake. It could be adjusted to provide more or less smoke and thereby control the quality of the air. For preliminary studies the laboratory air was used as a source of dirty air with considerable success.

Particulate matter appears to be much more objectionable in air when it is not the only cause of clogging. Table III is a tabulation of the effect of particulate matter taken from Figures 1 through 6. From these results it appears that in dry air the increase in clogging caused by particulate matter is effective only after an appreciable period of time, 5 to 11 days in these accelerated tests. It has been assumed that this period is the time required for enough pores to become filled to affect the air flow through the media. When the air is humidified the rate of clogging from particulate matter is greatly accelerated. This has been explained in the section on humidification. It also appears that there is no delay in clogging even with as little particulate matter as 0.07 mg /1,000 cu ft of air.

An estimate of the quantity of particulate matter required to increase the head loss (of a 1-ft tube) 22 in. over its initial loss was obtained by computing the amount of particulate matter discharged to the tube shown

TABLE III.—Effect of Particulate Matter on Rate of Clogging Diffuser Media

Figure No.	Clogging Material	Air Quality (mg/1,000 ft)	Humidity	Effect of Particulate Matter
1	Fe^{++}	4.7	Dry	For 6 days shown, no effect
2	Fe^{++}	5.0	Dry	After 5 days, increased clogging
5	Fe^{++}	.07	Partial	Increased clogging from beginning
6	Particulate matter	1.8 to 37.4	Dry	After 5 days, slight increase
			100%	After 5 days, considerable increase

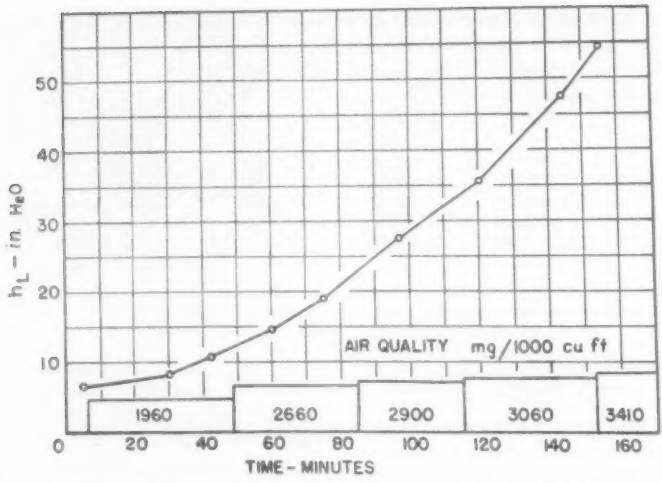

FIGURE 7.—Diffuser clogging rate with saturated air and high particulate content.

in Figure 6 over the 7-day period. This was compared to a similar tube (Figure 7) which was clogged to the same degree in 100 min. It required 875 mg of solids to clog the tube in 100 min and 555 mg to clog it in seven days. This was a very close agreement if corrections are made for the fact that with the high particulate concentration there was some precipitation on the pipe walls preceding the diffuser.

The clogging rate of particulate matter in dry air is much less than in humid air as shown by Figure 8. The variation of the pressure loss of the clean air tube is a result of the varying air flow to the tubes but the difference in pressure loss of the two tubes is due

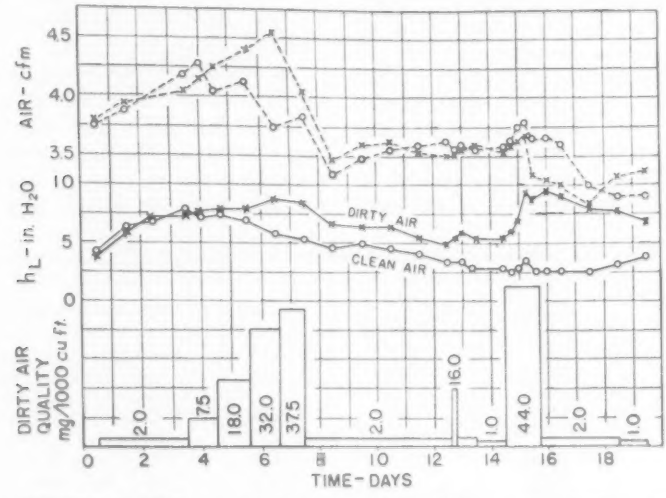

FIGURE 8.—Diffuser clogging rate with particulate matter in dry air.

to the clogging of the tube with particulate matter. It is apparent that there is a partial recovery each time the particulate matter is reduced. Prolonged tests would be necessary to get complete clogging of a diffuser with dry air and with concentrations in the range of the test.

Discussion

The information on iron clogging has confirmed that which was known from plant experience. Ferrous iron will result in external clogging. The elimination of this clogging apparently depends on the exclusion of ferrous iron from the sewer. It is an industrial waste that does not belong in a public sewer since it interferes with efficient plant operation.

The information on clogging rate caused by calcium bicarbonate hardness in the water supply is not as well understood, probably because it is not commonly encountered. Of these bicarbonates, only calcium is objectionable and is found in troublesome concentrations in few cities. The use of humidification and truly clean air may offer a solution to this type of clogging.

Sand clogging has been encountered in only a few plants in the United States, apparently because the small grain size sand found responsible is not present. The possibility of calcite cementing in connection with sand clogging should be investigated where sand is a problem. If it does contribute, corrective measures may be taken.

Clogging by particulate matter in the air supply is by far the most common cause of clogging in operating plants and for this reason the information gained on this subject is most valuable. It has been shown that particulate clogging is indeed serious and furthermore that it is dependent to a large extent on the relative humidity of the air supply. This explains why clogging has been accelerated at many plants during periods of warm humid weather. It is not the humidity that clogs the media but rather the particulate matter, which is more objectionable in the presence of moisture. This work indicates the importance of providing clean air for air diffusion since dehumidification is not practical.

The value of clean air has previously been pointed out by others but there has been no general acceptance of the need for clean air nor any general acceptance of how clean the air should be. Anderson (9) pointed out in 1950 that plates at the Chicago Southwest Plant supplied with air cleaned to a particulate matter concentration of 0.5 mg/1,000 cu ft lasted five times longer than plates supplied with 2.5-mg/1,000 cu ft air. Operation of this plant since then has proven the value of using even cleaner air.

When the Chicago Southwest Plant was first started, particulate material in the air supply resulted in the clogging of diffuser media so severe that at times plant operation was almost impossible. In 1950 this clogging problem was solved by pioneering the installation of precoated bag filters using asbestos "floats" as a precoat, to provide truly clean air.

Beck (10) has provided operating data from the Southwest Plant which shows the efficiency of precoated bag filters and proves the value of using truly clean air to eliminate diffuser clogging. This information is summarized in Tables IV and V.

TABLE IV.—Air Quality, Chicago Southwest Sewage Treatment Plant, from Annual Reports (9)

Year	Air Dust Concentration (mg/1,000 cu ft)		
	Raw Air	Filter Discharge	As Supplied to Aeration Tanks
1951	3.71	0.09	0.17
1955	10.9	0.04	0.04
1956	9.0	0.014	0.032

TABLE V.—Chicago Southwest Sewage Treatment Plant, Head Loss Across Diffuser Plates (9), Tank No. 2, Battery B

Date	Cumulative Air Flow Per Plate (million cu ft)	Rate of Air Flow Per Plate (cfm)	Plate Pressure Loss	
			At Tank Influent (psi)	At Tank Effluent (psi)
January 1950	5.0	3.19	0.23	0.21
March 1957	23.0	3.20	0.21	0.28

Summary and Conclusions

Air diffusion media has been clogged in the laboratory with particulate matter in the air supply, with fine sand in the tank liquor, with excessive calcium bicarbonate hardness in the water supply, and with ferrous iron salts in the sewage.

Particulate matter in the air supply has undoubtedly caused more media clogging in operating plants than any other single cause. It has been shown that the clogging rate from particulate matter, other factors being the same, is proportional to the quantity of the material in the air supply. It is also dependent to a large extent on the relative humidity of the air supply. Clogging with even moderate amounts of particulate matter may be extremely rapid if the air is saturated, whereas at 20 per cent relative humidity the same particulate matter results in only moderate clogging.

Plant operating records have shown that bag filters precoated with asbestos "floats" will supply air containing less than 0.10 mg of particulate matter per 1,000 cu ft of air. With this high-quality air, clogging from particulate matter will not be a problem. It is recommended that precoated bag filters be used for filtering air for aeration tanks and that they be specified to produce an air containing not more than 0.1 mg of particulate matter per 1,000 cu ft.

Ferrous iron, when present in the tank influent in sufficient concentrations, will definitely clog diffuser media. It is, therefore, an undesirable material as a part of incoming sewage.

Fine sand of 100-μ diameter or smaller will clog diffuser media. The clogging rate may be aggravated if hard water is present. If so, corrective measures may be undertaken. If sand alone is responsible, the media pore size can be changed to avoid the particle size encountered.

All forms of clogging investigated in this study were aggravated by particulate matter in the air supply. Therefore, it is important that air quality be carefully examined, and if necessary that high-quality air filters be provided before other corrective measures are undertaken. The corrective measures outlined above for specific causes of clogging can be effectively applied only with a clean air supply.

Acknowledgments

These studies were carried on in the State University of Iowa Sewage and Industrial Waste Laboratory and were financed by a research grant from the Chicago Pump Company, Chicago, Ill.

Mr. Miles Lamb provided information from the Chicago Pump Company files on clogging problems in operating plants and served as a consultant in planning the individual studies so that the results could be correlated with plant conditions.

Peter J. Neuspiel, Edgar A. Jeffrey, and David A. Long, Research Associates at the State University of Iowa during the two-year period of this study, conducted most of the laboratory work and wrote the 13 progress reports which provided the basic data for this report.

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NEW FEDERATION PUBLICATIONS

Two new Manuals of Practice are now available. The first of these is a revision of Manual of Practice No. 1, the Federation safety manual, originally issued in 1944, and is entitled "Safety in Wastewater Works." The second is the result of joint effort by the Federation and the American Society of Civil Engineers and is Manual of Practice No. 8, entitled "Sewage Treatment Plant Design."

When remittance accompanies order, the manual prices include postage. Send check or money order to the Federation office, made payable to FSIWA.

See page 76a of this issue for complete listing of Federation publications.

SAFETY IN WASTEWATER WORKS

The new safety manual is a 64-page publication following the general format of THIS JOURNAL. It has been completely revised so as to include the most useful information on this very important aspect of operation. The revision has been made by the Federation Safety Committee, J. J. Wirts, Chairman, under the general guidance of the Sewage and Industrial Wastes Practice Committee, chaired by Morris M. Cohn.

For several months orders for hundreds of these manuals have been on hand in the Federation office. These are now being filled as rapidly as possible. Prices are 75¢ to members and $1.50 to non-members.

SEWAGE TREATMENT PLANT DESIGN

The new design manual is the result of several years' work by the Federation Subcommittee on Sewage Treatment Plant Design of the Sewage and Industrial Wastes Practice Committee and the Sanitary Engineering Division of ASCE. The joint committee was headed by Daniel A. Okun.

This manual is a comprehensive summary of current practice in sewage treatment plant design and will be of great reference value. It will have approximately 350 pages, 6" × 9". Prices are $3.50 to members and $7.00 to non-members.

Industrial Wastes

DEVELOPMENT OF THE ANAEROBIC CONTACT PROCESS *

I. PILOT-PLANT INVESTIGATIONS AND ECONOMICS

By George J. Schroepfer and Norman R. Ziemke

Respectively, Professor of Sanitary Engineering, and Research Fellow in Sanitary Engineering, University of Minnesota, Minneapolis, Minn.

This paper summarizes the results of three years of research on the application of the anaerobic contact process in the treatment of various types of industrial wastes and of municipal sewage and will be published in two parts. Part I includes data from pilot-plant investigations and an economic analysis. Part II, to follow in an early issue, discusses other investigations and special experiments, summarizes the study, and offers the conclusions.

This investigation was supported by Research Grant No. 4419, from the National Institutes of Health of the Public Health Service.

Introduction

Apart from the usual concept of anaerobic processes employed in the digestion of the concentrated sludges produced by separation from the conventional processes of waste treatment, there have been employed for many years anaerobic treatment methods which varied from the historic septic tanks to the more controlled and understood processes suggested by Buswell for the "digestion of industrial wastes." † As a result of experience in the intervening period, Buswell (1) presented in 1949 the results of his experience in the treatment of yeast and grain wastes in several plants in the Midwestern area.

Encouraged by Buswell's results, W. J. Fullen, Chemist of George G. Hormel and Company, began in 1950 a series of small-scale pilot-plant tests on packing plant wastes. These were sufficiently promising to encourage the American Meat Institute to embark in 1952 on a program of investigation and evaluation of the process as applied to this type of waste, under the direction of the present investigators.

Up to this stage of practice, the actions involved were not separated into distinct unit operations or processes. The concept of a contact process as distinguished from a separation process and their interrelation did not exist. Consequently, long detention periods and low loadings were necessary. As a result of the large-scale pilot-plant tests at the Hormel plant from 1952 to 54, a series of reports were presented to the American Meat Institute, which are summarized and published (2).

In 1956 a full-scale plant was constructed at the Wilson and Company

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

† U. S. Patent 2,029,702 (Jan. 23, 1932).

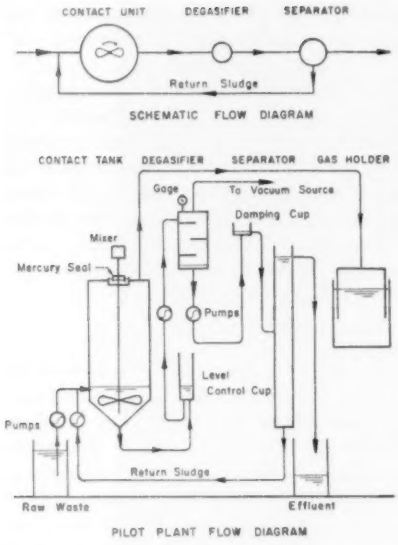

FIGURE 1.—Schematic and pilot-plant flow diagrams for anaerobic contact process.

packing plant at Albert Lea, Minn., embodying the basic flow diagram which resulted from the research. The design of this plant has been described by Steffen (3). The results of the first year's operation have surpassed those predicted from pilot-plant operations.

In a comparison of the anaerobic contact process and the activated sludge process it is found that the two are similar except that an anaerobic environment is maintained in the former. Essentially, the anaerobic contact process involves two parts, a contact portion where the raw waste is intimately mixed with a previously developed anaerobic sludge culture, and a separation portion where the active sludge particles are separated from the treated liquor and recycled to the contact unit. Various modifications of the process are possible from the standpoint of the flow diagram and the arrangement and type of units; however, in this report, the term "anaerobic contact process" will refer to a standard flow diagram which includes a contact unit, a vacuum degasifier unit, and a gravity separation unit, arranged in that order as shown in the schematic flow diagram in Figure 1.

Previous research and pilot-plant investigations on the treatment of packing plant wastes by the anaerobic contact process have been reported by Schroepfer *et al.* (2). This report concluded that under proper conditions the process was economically applicable to packing plant waste and showed enough promise to warrant further study, especially in extending its application to other typically organic industrial wastes and sewages and in furthering the understanding of the basic actions and mechanisms involved in the process.

Research Objectives and Plan

The broad objective of the present research program was to study the factors affecting the efficiency and economics of the anaerobic contact process as applied to various sewages and industrial wastes. More specifically, the research goals for this program could be stated as follows:

1. To extend the application of the anaerobic contact process to certain other industrial wastes and sewage, and to study and evaluate the factors which affect the efficiency and economics of the process. On a practical basis, this would be aimed at determining parameters which could be used in designing and operating a large-scale installation.

2. To investigate the basic actions involved in the biological or contact portion and separation portion of the process and determine, if possible, the kinetics and mechanisms of the specific physical, chemical, and biological reactions which take place.

It was felt that any research program designed to accomplish these goals would of necessity be built around a continuous flow investigation

of the anaerobic process in a laboratory-scale pilot plant. The basic plan was to design and operate several pilot plants of the anaerobic contact process so that all of the operating variables could be controlled over a wide range with a high degree of flexibility. The pilot-plant test program was designed to determine on a practical basis whether a particular waste was amenable to anaerobic treatment and to determine the effect of a number of operating variables on the process efficiency and economics.

In addition to the pilot-plant studies, a program of special experiments and ancillary investigations were carried out using active sludges taken from the pilot plants. These tests were aimed particularly at furthering the understanding of basic actions which occur in the anaerobic contact process.

Pilot-Plant Investigations

The major part of the laboratory-scale pilot-plant investigations reported in this study was made using the standard anaerobic contact process as described earlier. During the three-year research program, a total of 10 test series was carried out. The type of waste treated and the operating temperature which was used in each test series are given in Table I. Test Series 8 and 9 involved the use of a different flow diagram and will be discussed separately in a later section.

TABLE I.—Waste Types and Operating Temperatures Used in Laboratory Test Series

Test Series	Waste Treated	Contact Unit Operating Temp. (°C)
1	Packing plant	35
2	Packing plant	35
3	Packing plant	35
4	Synthetic milk	35
5	Packing plant	25
6	Synthetic milk	25
7	Fatty acid	35
10	Wood fiber	35

Description of Pilot Plants and Test Procedures

Two identical laboratory-scale pilot plants of the anaerobic contact process were designed and constructed to carry out this phase of the research program. The pilot plant is described by the flow diagram (Figure 1) and the photograph (Figure 2).

In the laboratory-scale pilot process, the raw waste was introduced directly into a sealed, insulated digester or contact unit where it was continuously mixed with previously developed anaerobic sludge and maintained at any desired constant temperature with external heating or cooling coils. This unit was cylindrical, about one foot in diameter, with a cone-shaped bottom, designed so that the operating volume could be varied from 0.2 to 2.0 cu ft. As an aid to positive separation, the effluent from the contact unit was fed continuously to a cylindrical degasifier unit which was equipped with splash trays and a water ejector vacuum source in order to remove gas bubbles from the sludge particles. The degasified effluent was then allowed to settle in a separator tube from which the clarified effluent was drawn off at the top, and the sludge which settled to the bottom was continuously recycled to the contact unit. Five separator tubes of different diameters and of several depths were available to allow flexibility in separator loading. The flow rates for raw feed and return sludge were maintained constant at any desired level from 4.0 to 400 ml/min by three variable speed pumps.* The gas produced in the contact unit was collected and measured in a floating cover gas holder. The design of the pilot plants made provision for a high degree of flexibility and accurate control of all the operating variables.

* Sigmamotor.

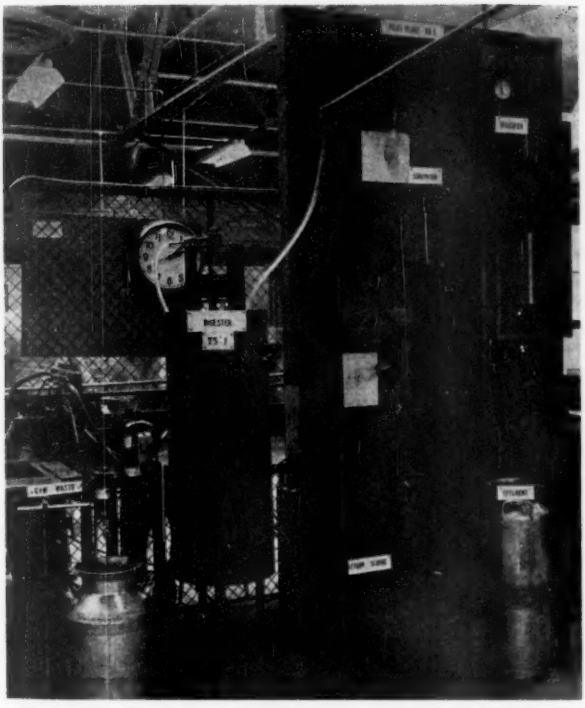

FIGURE 2.—Operating arrangement for laboratory pilot plant for anaerobic contact process.

To simulate usual industrial operating conditions during most of the research program, the routine operation of the pilot plants was on a continuous 24-hr basis during week days with attendance during the normal 8-hr working day only. Over week-end periods and on holidays, the plants were generally shut down, except when special tests were underway, and all of the sludge culture was placed in the contact unit to maintain a constant temperature environment. Flow rates were measured and adjusted and samples were taken at various points in the process each 24-hr period. Care was exercised in measuring and adjusting the various conditions of operation and in taking samples in order to represent the actual conditions which prevailed during each test run. To insure equilibrium conditions during each test, the individual tests on the pilot plants were generally allowed to continue for a period of several weeks during which the operating conditions were maintained as nearly constant as possible. In general, the laboratory analyses of the daily samples were made in accordance with the procedures outlined in "Standard Methods" (4). The routine laboratory determinations made on the various samples included: BOD, COD (dichromate), solids in various forms, ammonia and organic nitrogen, turbidity, volatile acids, pH, and alkalinity.

Raw Waste Characteristics

During the pilot-plant test program, a number of actual and synthetic wastes were fed to the pilot plants in

order to determine their treatability and to study the economics of applying the process to different types of wastes on a large scale. From a practical standpoint, the results obtained using actual "run-of-the-plant" waste would probably be more reliable in predicting the performance of a large-scale installation. However, the use of synthetic wastes also offered certain advantages such as convenience in handling and the elimination of the cost of collecting and transporting raw waste samples. Also, and probably more important, the synthetic waste could be made up uniformly each day to any desired strength, and the pilot plants could be operated at more uniform and controlled conditions. This would allow a closer study of some of the effects which might in some cases have been obscured by the normal variations in strength of naturally occurring plant wastes.

Packing Plant Wastes

The first series of pilot-plant tests in this program were made using packing waste as a raw feed. Earlier work (2) formed the basis for the belief that the use of this waste would serve as a good starting point for initiating the pilot-plant testing program and in establishing proper operating procedures.

The packing plant waste used for these studies was collected at the sewage plant at South St. Paul, Minn., which consisted of packing plant wastes of Swift and Company, Armour and Company, and several small packing plants, plus the commercial and domestic wastes from a community of about 15,000 population. The average analysis of this waste as it was fed to the pilot plants during the tests of Series 3 and 5 is shown in Table II.

Fatty Acid Wastes

The fatty acid waste used as a raw feed in the pilot-plant investigations during Series 7 was obtained from the

TABLE II.—Analysis of Certain Wastes Used as Raw Feed for Pilot-Plant Studies

Determination	Test Series															
	(Packing Waste)			(Packing Waste)			(Fatty Acid Waste*)			(Domestic Sewage)			(Wood Fiber Waste)		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Tot. solids (ppm)	3,161	4,462	934	3,118	4,172	1,686	15,067	59,012	3,568	1,045	2,472	654	4,711	6,478	2,968
Tot. vol. sol. (ppm)	1,396	2,148	836	1,149	2,148	502	4,371	16,638	218	355	600	112	3,383	5,570	668
Susp. solids (ppm)	826	2,032	26	759	2,032	184	1,214	6,598	136	426	1,254	126	1,226	3,636	32
BOD (ppm)	1,237	2,132	304	896	1,778	414	6,277	15,500	2,463	273	464	151	2,472	3,630	1,630
COD (ppm)	—	—	—	—	—	—	9,567	24,000	4,160	698	1,540	353	5,857	8,000	3,540
pH	7.23	8.80	5.32	7.51	8.80	6.65	6.10	7.40	4.10	7.41	7.78	6.09	6.32	8.12	5.42
Total N (ppm)	98	143	67	98	143	67	179	1,379	11	20	28	10	101	123	71
NH_3—N (ppm)	29	69	13	29	69	13	120	1,760	3	9	15	4	79	115	53
Alkalinity (ppm)	487	880	42	539	880	340	—	—	—	—	—	—	—	—	—

* As received.

Chemical Division, General Mills Inc., Kankakee, Ill. The waste is produced during the manufacture of certain fatty acid derivatives. The pH of this waste was adjusted to 7.5 with sodium hydroxide before it was fed to the process. The average analysis of this waste based on 58 daily samples is shown in Table II.

Wood Fiber Wastes

The waste used in Test Series 10 was produced in the manufacture of a pressed wood hardboard by the Superwood Corporation, Duluth, Minn. The raw material for this manufacturing process is pulp wood which is pulped and pressed into a finished hardboard by a wet process. The samples were collected each week day from the plant effluent and were composited in accordance with the flow. The pH of this waste was adjusted to 7.5 with sodium hydroxide before being fed to the process. Also, in all but the first test during which the process failed, the waste was fortified with one part of nitrogen per 20 parts of BOD and one part of phosphate per 100 parts BOD. The average analysis of this waste after being fortified with nitrogen and phosphate is shown in Table II.

Domestic Sewage

The domestic sewage used as a raw feed material during Test Series 9 was obtained at the Minneapolis-St. Paul sewage treatment plant. The samples were grab samples collected each day at 4 PM from the influent channel to the sedimentation tanks and kept overnight in cold storage. The average analysis of the sewage as fed to the pilot plants is given in Table II.

Synthetic Milk Wastes

The synthetic milk waste used for some of the pilot-plant studies was made by dissolving a measured quantity of nonfat instant dried milk solids in tap water. Sodium bicarbonate was added to provide approximately 500 ppm alkalinity, expressed as calcium carbonate, to act as a buffering agent. Using this procedure, a waste of any desired organic strength could be made. The daily analysis of this raw waste showed the following average analysis based on the bulk dry weight of dried milk: total solids, 97 per cent; total volatile solids, 83 per cent; suspended solids, 9 per cent; water, 3 per cent; total nitrogen, 4 per cent; BOD, 78 per cent; and COD, 98 per cent.

Factors Affecting the Effectiveness of the Anaerobic Process

The anaerobic contact process as described previously is a biological treatment process which makes use of an anaerobic sludge culture for the removal and stabilization of organic matters contained in a waste. It has been demonstrated that effective operation of this process is dependent on two somewhat independent actions. These are: (a) the adsorption and subsequent stabilization of organic matter, by an active biological culture, which takes place in the contact portion of the process and (b) the effective separation and concentration of the active sludge particles from the treated liquor which takes place in the separation portion of the process. In the flow diagram of the anaerobic process, these two actions are carried out in two distinct units, the contact unit and the separation unit. Since the actions which occur and the factors which affect the efficiency of action in each of these portions appear to be somewhat independent, the pilot-plant research program was set up so that each part of the process could be studied and analyzed independently or in combination.

Biological Contact Portion of the Process

Although it is recognized that biological action is not limited entirely to the contact portion of the process,

it is felt that the major portion of the removal and stabilization of organic matter occurs in this unit. On this basis, it is of primary concern to foster the growth of an active anaerobic sludge culture and to provide a favorable environment so as to secure an efficient and economical over-all process.

Parameters of Removal and Loading for the Contact Unit

Since the actions which are initiated and maintained by the biological life in the contact unit are largely responsible for the reduction in the organic content of a waste, the most significant measure of removal for this unit would be the degree to which the organic content of the waste, as measured by the BOD, COD, and total volatile solids determinations, is reduced. These determinations of organic strength are not reliably comparable for different wastes, and in this report the effectiveness of the contact unit has been evaluated for the most part on the degree of BOD removal.

Previous experience with biological treatment systems and the results of the pilot-plant investigations of the anaerobic contact process have demonstrated that the most significant loading parameters for biological units are the organic or the biological loading. The contact unit loadings which were selected for analysis in this report are the organic loading expressed as the pounds of organic matter (BOD) fed per day per cubic foot of effective contact unit capacity, and the biological loading in terms of the sludge age, expressed as the pounds of active sludge (suspended solids) in the system per pound of organic matter (BOD) fed per day.

Time to Acclimate Seed Sludge

In all of the pilot-plant investigations, the original seed or inoculant sludge was taken from an actively operating sludge digestion tank at a municipal sewage treatment plant. The seed sludge for the pilot-plant test on packing plant waste was obtained from the digestion tanks at the Austin, Minn., sewage treatment plant. In all of the remaining tests the seed sludge was obtained from the Anoka, Minn., sewage plant.

The procedure used to acclimate the seed sludge to a particular waste was similar in each test series. The seed sludge was placed in the contact unit and rinsed continuously for several days with dechlorinated tap water. Following this, the sludge was acclimated in the pilot plant by feeding dilute mixtures of the waste to be treated at low BOD loadings (0.01 to 0.02 lb per day/cu ft) for a period of one to three weeks. The actual test series for each particular waste was then initiated. The results indicate that a certain amount of time is necessary to acclimate a seed sludge to a new raw feed; however, when starting with relatively low loadings and using an actively digesting sewage sludge as a seed culture it appears that proper acclimation to higher loadings can be obtained in a period of a month or less.

Effect of Contact Unit Loading

Of the eight pilot-plant test series, six were designed primarily to study the effect of the contact unit loading on the BOD removal using various different wastes as raw feed. Of these, four test series were designed to use a contact unit operating temperature of 35°C. These test series were designated as 3, 4, 7, and 10, using packing plant waste, synthetic milk waste, fatty acid waste, and wood fiber wastes, respectively, as the raw feed material. Test series 5 and 6 were carried out to determine the operational effectiveness at a temperature of 25°C using packing plant waste and synthetic milk wastes, respectively.

Each test series consisted of a number of individual test runs, each con-

TABLE III.—Summary of Contact Unit Performance for Packing Waste—Test Series 3 Operated at 35°C

Test No. (1955–56)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)		Det. Period in Contact Unit (hr)		Removal (per cent)		
			Contact Unit		Total Volume								
	Temp. (°C)	Susp. Solids (ppm)	BOD	Tot. Vol. Solids	BOD	Tot. Vol. Solids	BOD	Tot. Vol. Solids	Raw Flow	Total Flow	BOD	Tot. Vol. Solids	Susp. Solids
1 (Dec. 13–Jan. 3)	33	10,800	0.334	0.314	0.168	0.158	3.97	4.21	7.05	1.82	88.2	79.7	90.5
7 (Feb. 6–Mar. 8)	35	11,210	0.239	0.322	0.114	0.160	5.98	4.46	6.60	1.56	89.7	79.3	90.2
8 (Mar. 12–Apr. 20)	35	7,512	0.0878	0.126	0.068	0.097	6.85	4.76	15.7	5.03	94.2	70.0	81.0
9 (Apr. 23–May 11)	36	11,467	0.264	0.308	0.158	0.186	4.75	4.07	6.81	1.73	90.1	71.4	78.1
10 (May 21–29)	38	8,486	0.114	0.144	0.0678	0.086	8.07	6.37	11.64	3.88	90.8	68.5	83.5

TABLE IV.—Summary of Contact Unit Performance for Milk Waste—Test Series 4 Operated at 35°C

Test No. (1956)	Contact Unit		Loading (lb per day/cu ft)						Sludge Age (days)			Det. Period in Contact Unit (hr)		Removal (per cent)			
			Contact Unit			Total Volume											
	Temp. (°C)	Susp. Solids (ppm)	BOD	COD	Tot. Vol. Solids	BOD	COD	Tot. Vol. Solids	BOD	COD	Tot. Vol. Solids	Raw Flow	Total Flow	BOD	COD	Tot. Vol. Solids	Susp. Solids
3 (Sept. 10–15)	34.1	4,061	0.048	—	0.069	0.0307	—	0.0442	8.85	—	6.13	7.20	2.05	99.1	—	54.5	51.2
4 (Sept. 17–22)	34.0	4,208	0.073	—	0.089	0.045	—	0.055	6.16	—	5.06	6.73	1.98	97.8	—	57.5	41.9
5 (Sept. 24–Oct. 12)	34.7	5,687	0.151	—	0.207	0.093	—	0.127	4.03	—	2.94	3.39	0.88	91.1	—	36.6	48.6
7 (Oct. 29–Nov. 10)	36.0	10,002	0.237	0.276	—	0.145	0.171	—	4.34	3.71	—	7.20	2.78	91.5	86.2	—	58.4
8 (Nov. 12–20)	35.7	10,134	0.276	0.330	—	0.169	0.202	—	3.76	3.14	—	7.35	2.75	86.0	86.6	—	57.1

TABLE V.—Summary of Contact Unit Performance for Fatty Acid Waste—Test Series 7 Operated at 35°C

Test No. (1957)	Test Duration (hr/day)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)		Contact Unit Det. Period (hr)		Removal (per cent)	
				Contact Unit		Total Volume							
		Temp. (°C)	Susp. Solids (ppm)	BOD	COD	BOD	COD	BOD	COD	Raw Flow	Total Flow	BOD	COD
2 (June 11–14)	23.63	35.9	10,082	0.048*	0.073	0.041*	0.063	13.30*	8.63	139.6	43.6	94.7*	94.7
3 (June 17–21)	24.22	35.0	10,433	0.069*	0.106	0.059*	0.091	9.40*	6.09	152.5	48.9	89.4*	89.4
4 (June 24–July 5)	24.02	34.5	13,116	0.113*	0.173	0.094*	0.144	7.28*	4.73	80.9	29.0	87.7*	87.7
5 (July 8–15)	24.45	35.1	17,207	0.222*	0.341	0.171*	0.263	5.00*	3.25	44.1	14.8	89.1*	89.1

* Computed from COD determinations assuming BOD = 0.65 COD for both raw feed and effluent.

TABLE VI.—Summary of Contact Unit Performance for Wood Fiber Wastes—Test Series 10 Operated at 35°C

Test No. (1958)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)			Contact Unit Det. Period (hr)		Removal (per cent)			
			Contact Unit		Total Volume										
	Temp. (°C)	Susp. Solids (ppm)	BOD	COD	BOD	COD	BOD	COD	Tot. Vol. Solids	Raw Flow	Total Flow	BOD	COD	Tot. Vol. Solids	Susp. Solids
3 (Jan. 20–Feb. 28)	35–37*	8,777	0.0486	0.118	0.0355	0.0856	13.90	5.75	8.58	79.5	38.2	83.3	76.7	82.3	55.1
4 (Mar. 3–20)	35–36†	7,262	0.1050	0.204	0.0745	0.144	5.59	2.88	4.18	38.0	19.2	76.6	67.0	83.3	79.0
5 (Mar. 24–28)	35–39.5‡	6,679	0.144	0.238	0.108	0.177	4.17	2.53	17.00	28.2	13.8	78.1	70.9	24.2	89.6
6 (Mar. 31–Apr. 9)	36.5–37	8,785	0.216	0.525	0.162	0.394	3.71	1.52	2.55	16.30	7.98	45.0	53.5	68.7	53.6

* Temperature 49°C in middle of run. † Temperature 48°C one day in middle of run. ‡ Temperature 25°C one day.

tinuing for a period of a week or more. Generally, the procedure was to start with low loadings and to increase the loading progressively in each successive test. The original plan was to follow this procedure to the point where the process would begin to fail. However, because of the difficulty in securing seed sludge and the time required to acclimate it, the loading generally was not carried to the actual point of complete failure of the process.

1. Operating temperature of 35°C. The summary of the contact unit loadings and removals for test series 3, 4, 7, and 10 are shown in Tables III, IV, V, and VI. The data shown are the averages of individual daily results obtained during each test run. In this report, the analysis of the contact unit loading and removal is made on a BOD basis only, even though determinations of other measures of the organic strength were made during many of the tests.

The effect of the contact unit loading on the BOD removal of the anaerobic contact process is shown in Figure 3 for the test series using packing plant waste, synthetic milk waste, fatty acid wastes, and wood fiber wastes as raw feed. Although the data in each case are limited to four or five points, a trend of a decreasing efficiency with increased loading is quite apparent. A linear regression line has been selected to fit the plotted points. The equation for the linear regression line has been computed in each case and is shown on the figure together with the coefficient of correlation, r. The relatively high value for the coefficient of correlation, even for the limited amount of data in each case, indicates that over the range of data, a linear regression line fits the data quite well.

In a comparison the trend described by the data for packing plant, synthetic milk, and fatty acid wastes appears similar. In each of these cases, the data indicate that at a contact unit

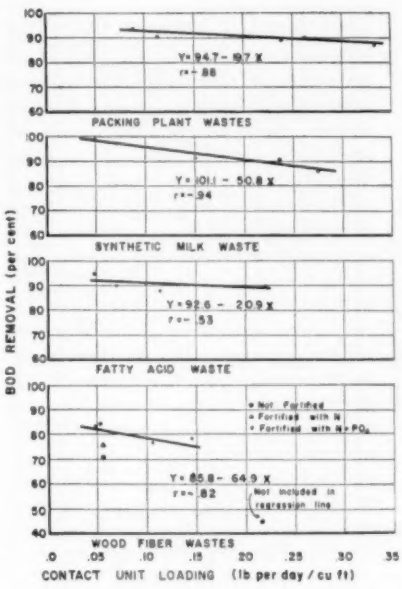

FIGURE 3.—Effect of loading on BOD removal in contact unit at 35°C.

loading of about 0.20 lb per day/cu ft the expected removal efficiency of the process would be about 90 per cent. For wood fiber wastes, the trend line is considerably lower and indicates that even at extremely low loads a removal efficiency of 90 per cent cannot be obtained. This waste as produced has a pH of 4.0 to 5.0 and contains very little nitrogen or phosphorus as compared to its high BOD. The trend was computed from results on the waste with the pH adjusted to 7.5 and fortified with nitrogen and phosphorus. The results of the first two tests in this series on non-fortified waste are shown on the figure and demonstrate clearly the need for nitrogen and phosphates for efficient bacterial action.

The degree with which the contact unit loading affects the removal in each case is indicated by the slope of the trend lines. These show a drop of about 2 per cent for packing plant and fatty acid wastes, 5 per cent for

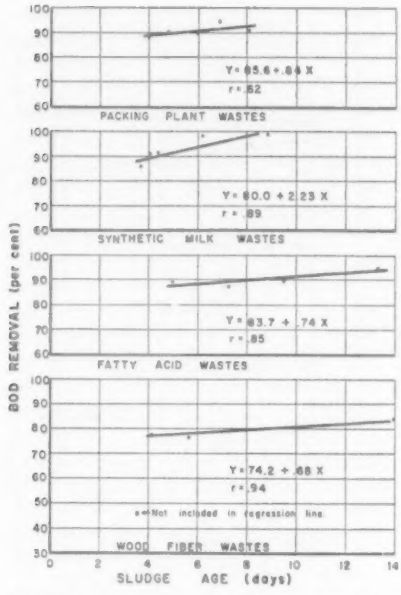

FIGURE 4.—Effect of sludge age on BOD removal in anaerobic contact process.

synthetic milk waste, and 6.5 per cent for wood fiber waste for each increase in loading of 0.10 lb per day/ cu ft. It should be pointed out, however, that it would be unwise to extrapolate the data beyond the range of actual results, especially since there is evidence that if the loading is carried beyond a certain point, the process efficiency will fall off sharply. This fact is demonstrated by one of the wood fiber tests shown as an open point on the figure.

Figure 4 shows the effect of loading in terms of sludge age on the BOD removal for these same data. It is readily apparent that over the range of data collected, the sludge age has a consistent effect on the BOD removal. As might be expected, a decrease in sludge age is accompanied by a decrease in treatment effectiveness. Again, the trend in each case has been described by a linear regression line and equation. The computed coefficients of correlation indicate a reasonable fit of the linear regression line with the data in each case. However, it would seem logical to expect that there would be no BOD removal at zero sludge age. This might indicate that below a limiting sludge age, the degree of treatment would drop sharply. The lowest sludge age encountered was about three and one-half days which, in the case of wood fiber waste, resulted in a marked decrease in BOD removal. In general, it appears that a sludge age of four days or more is required for efficient biological action.

2. Operating temperature of 25°C. The summary of contact unit loadings and removals for test series 5 and 6 which used an operating temperature of 25°C are shown in Tables VII and VIII. Packing plant waste and synthetic milk waste were treated in test series 5 and 6, respectively.

The effect of loading and sludge age on the BOD removal of the process for these two tests is shown in Figure 5.

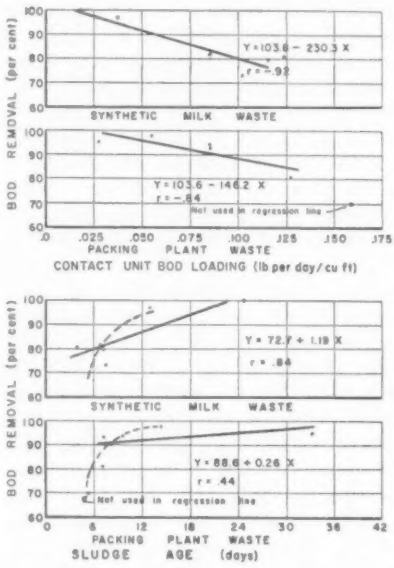
BOD REMOVAL (per cent)
Y = 103.6 − 230.3 X
r = −.93
SYNTHETIC MILK WASTE
Y = 103.6 − 146.2 X
r = −.64
Not used in regression line
PACKING PLANT WASTE
CONTACT UNIT BOD LOADING (lb per day/cu ft)
Y = 72.7 + 1.19 X
r = .84
Y = 88.6 + 0.26 X
r = .44
Not used in regression line
SLUDGE AGE (days)

FIGURE 5.—Effect of loading and sludge age on BOD removal in contact process at 25°C.

TABLE VII.—Summary of Contact Unit Performance for Packing Waste—Test Series 5 Operated at 25°C

Test No. (1956)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)		Det. Period in Contact Unit (hr)		Removal (per cent)		
			Contact Unit		Total Volume								
	Temp. (°C)	Susp. Solids (ppm)	BOD	Tot. Vol. Solids	BOD	Tot. Vol. Solids	BOD	Tot. Vol. Solids	Raw Flow	Total Flow	BOD	Tot. Vol. Solids	Susp. Solids
1 (Mar. 14–Apr. 20)	26.7	13,800	0.0274	0.0368	0.0258	0.0348	33.30	24.80	55.6	12.8	95.6	74.7	85.7
2 (Apr. 25–May 4)	24.5	11,294	0.0552	0.0684	0.0496	0.0615	14.30	11.52	27.56	7.21	97.9	79.3	88.6
3 (May 7–10)	23.4	11,298	0.0856	0.1092	0.0733	0.0935	9.65	7.57	18.70	4.19	94.1	70.1	90.0
4 (May 15–30)	25.6	7,948	0.0857	0.1114	0.0682	0.0885	7.30	5.60	17.03	3.72	93.4	75.9	90.0
5 (June 18–22)	25.1	10,306	0.1271	0.1781	0.0884	0.1239	7.10	5.07	8.55	2.29	81.1	70.8	89.7
6 (June 25–29)	24.5	9,272	0.1583	0.2003	0.1042	0.1318	5.34	4.23	6.86	1.85	69.9	59.0	76.2

TABLE VIII.—Summary of Contact Unit Performance for Milk Waste—Test Series 6 Operated at 25°C

Test No. (1956)	Contact Unit		Loading (lb per day/cu ft)						Sludge Age (days)			Det. Period in Contact Unit (hr)		Removal (per cent)			
			Contact Unit			Total Volume											
	Temp. (°C)	Susp. Solids (ppm)	BOD	COD	Tot. Vol. Solids	BOD	COD	Tot. Vol. Solids	BOD	COD	Tot. Vol. Solids	Raw Flow	Total Flow	BOD	COD	Tot. Vol. Solids	Susp. Solids
1 (Sept. 10–15)	26.5	4,918	0.0192	—	0.0568	0.0219	—	0.0337	24.7	—	9.45	8.32	2.04	100	—	42.4	−13
2 (Sept. 17–21)	24.0	5,016	0.0371	—	0.0528	0.0257	—	0.0365	13.0	—	9.20	8.21	1.82	97.2	—	30.2	54.6
3 (Sept. 23–Oct. 6)	23.1	6,120	0.0849	—	0.3001	0.0588	—	0.2078	6.92	—	1.95	2.80	1.28	81.7	—	24.1	−2.1
4 (Oct. 8–12)	21.7	5,372	0.123	—	0.2513	0.0856	—	0.1741	4.021	—	1.98	2.25	1.61	80.5	—	53.7	17.7
7 (Nov. 1–17)	24.0	8,505	0.1037	0.1309	—	0.073	0.0906	—	7.60	5.99	—	9.34	4.90	73.2	79.8	—	37.3
8 (Nov. 19–30)	21.0	8,845	0.1154	0.1597	—	0.0801	0.1107	—	7.18	5.04	—	3.45	1.80	79.4	71.5	—	−134

Although the data are somewhat more scattered than those obtained at 35°C, the general trend is similar, showing a decrease in BOD removal with an increase in contact unit loading or a decrease in sludge age. The trend in each case has again been described with a computed linear line of regression together with the equation and coefficient of correlation. In general, the data indicate that at an operating temperature of 25°C, a 90 per cent BOD removal can be obtained at a contact unit loading of about 0.07 lb per day/cu ft for milk waste or 0.09 lb per day/cu ft for packing plant waste. The effect of sludge age is not as well defined because much of the data are at or near the critical value where the efficiency begins to decrease. In both cases, a curved line as indicated by the dotted line might be more representative of the data variation.

Effect of Solids Concentration

Since the sludge age is directly related to the solids concentration in the system, it is evident from the data presented that the solids concentration in the system has a direct effect on the effectiveness of the process. In the pilot-plant tests, the maximum obtainable solids concentration in the contact unit was a direct function of the degree of concentration that could be achieved in the separation unit. Since most of the pilot-plant tests were carried out using gravity separation, the maximum suspended solids concentration that could be maintained in the contact unit was about 15,000 ppm. Up to this concentration, it appeared that the solids maintained in the system had a direct effect on the BOD removal. In order to check the effect of solids concentration directly at somewhat higher solids concentrations, a test was run using centrifuge separation, where it was possible to maintain 30,000 ppm suspended solids in the contact unit. This test was compared with other tests with equivalent contact loading but with lower solids concentrations. In general, the results of this comparison showed that at these high solids concentrations the degree of BOD removal is not improved with increasing solids. Apparently, there is a limiting concentration of solids that can be used effectively in this process. There are logical reasons which could be used to explain this: (a) at extremely high solids concentrations, it is difficult to mix intimately the sludge particles and the raw feed, and (b) there is the possibility of a build-up of metabolic products which might have an inhibiting effect on the activity of the organisms.

Effect of Temperature

It is common knowledge that most chemical reactions are accelerated at higher temperatures. However, biological or biochemical reactions are generally limited to the rather narrow temperature range of 0 to 40°C. In this range it has been generalized that chemical reaction rates are about doubled for each 10°C rise in temperature. The rates of biochemical and enzyme reactions have also been found to be influenced to varying degrees by temperature. Since the removal and subsequent stabilization of a mixture of organic matter contained in a waste by a mixed culture of organisms is a very complex and heterogeneous system of reactions and interactions, it would be very difficult to predict the effect of temperature on the BOD removal of the anaerobic contact process. For this reason, several pilot-plant test series were designed to investigate this effect under continuous flow operating conditions.

The pilot-plant tests using packing plant waste and synthetic milk wastes have been discussed previously in analyzing the effect of loading. The results of the same data in Test Series 3, 4, 5, and 6 can also be compared to determine the effect of temperature of operation on the effectiveness of the

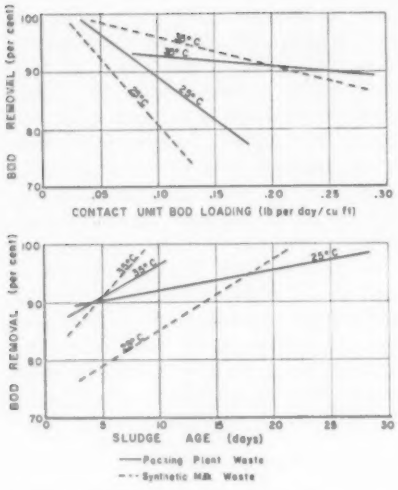

FIGURE 6.—Effect of temperature on BOD removal.

process for packing plant waste and for synthetic milk waste. For ease of comparison the effect of loading and sludge age on removal for these four test series are given in Figure 6. The lines shown are the linear regression lines which were computed and discussed previously. A comparison of the results at 25°C and 35°C for packing plant and synthetic milk wastes demonstrates clearly the marked effect of temperature on BOD removal. Admittedly, based on the limited amount of data which define each trend, only an approximation of the effect of temperature can be made. However, based on these data it is interesting to compare the maximum loading possible to obtain a 90 per cent BOD removal.

For example, these data indicate that the rate of anaerobic stabilization is increased about 2.5 times for packing plant waste and about 3.5 times for synthetic milk waste for a 10°C temperature rise.

Previous reports on the anaerobic stabilization of organic matter by several investigators indicated that a fairly constant temperature environment is necessary to develop and maintain a healthy active anaerobic sludge culture. Since the thermal requirements of the process are of real economic importance, the question arises as to the effect of hourly or daily temperature variations, such as might be expected in an actual waste produced by an industry. A special pilot-plant test under Series 4 was designed to determine the effect of hourly temperature variations on the performance of the process. In order to simulate a typical hourly temperature variation pattern, the contact tank was heated to 35°C during 10 daylight hours and allowed to approach room temperature (24°C) during the night. In general, the results of this test showed a gradual breakdown of the process because of the temperature variations. In one week of operation, the BOD removal dropped progressively from 80 to 68 per cent, and the volatile acids increased from 100 to 500 ppm. The obvious conclusion from this test is that the process is not tolerant to a 10°C (diurnal) temperature variation.

Effect of Mixing

It is generally agreed that much of the biological life in an anaerobic sludge is attached to and associated with the flocculent sludge particles and is not floating free in the substrate. Further, it is believed that the reactions which occur, particularly those of adsorption, take place on the surface of the sludge particles. Since the sludge particles in anaerobic sludge tend to separate from the substrate by floating or settling, mixing is important to achieve maximum contact between the waste and the sludge particles. The large-scale pilot-plant tests carried on at the Hormel plant in 1952–54 (2) showed a marked reduction in the degree of BOD removal by a gradual decrease in the number of contact tank turnovers from 66 to 20 per day.

It was difficult to design a test on

the scale of these pilot plants to measure directly the effect of the degree of mixing on the effectiveness of the process. In the tests made with anaerobic sludge during these pilot-plant studies, two general observations have been made regarding mixing. First, if mixing is not provided the sludge separates into a heavy floating layer, a relatively dilute internatant layer, and a heavy settled layer. Second, violent turbulent mixing tends to break up the sludge floc into fine particles; however, the floc appears to re-form in a matter of a few minutes after mixing is stopped. Regarding the effect of the latter factor, it is believed that efficient mixing is essential to achieve intimate contact between the food supply and the active sludge.

Effect of Variations in Loading

In general, it was attempted to maintain the loading conditions as constant as possible during each test period. However, in using actual "run-of-the-plant" wastes, this was not possible due to normal variations in waste strength. The day-to-day variations of packing plant waste varied as much as three times the average load. These variations in daily loading did not appear to upset the process. Also, during some of the earlier tests on packing plant wastes the treatment units were fed at high rates during the day only, with no feed at night. The results of these tests also indicated that the process was capable of absorbing shock loads.

One interesting point regarding loading developed because of the practice of shutting down the pilot plants over the week ends. The results of many of the tests indicated that under nearly constant loading conditions the effectiveness of the process gradually decreased during the week, but recovered quickly after the week-end rest period. In order to check the effect of these shutdowns, several tests were designed to operate the pilot plants on a continuous seven-day week. The results of these tests showed the same gradual decrease in treatment degree during the first five days of operation followed by a slightly lower equilibrium level during the remainder of the tests. This would indicate that the week-end rest periods or periods of low feed are generally beneficial to the process but are not necessarily essential to efficient operation.

Effect of Loading on Physical Quality of Effluent

An efficient waste treatment process, in addition to providing an effluent containing low solids and low organic strength should provide an effluent with physical characteristics which will not cause nuisance conditions in a receiving water. The physical characteristics of importance in this respect are color, clarity, and odor. Since anaerobic decomposition has generally been associated with offensive odors, this problem was considered in the investigation.

With regard to the color and clarity of the effluent, several general observations might be made. In strong wastes a high color in the raw waste does not appear to be changed by the treatment process. This was true with the yellow or brownish cast of fatty acid and wood fiber wastes and with the colorless synthetic milk wastes. The effluent was clear in the case of packing plant and milk wastes but somewhat cloudy in the case of fatty acid and wood fiber wastes. The turbidity of the effluent appeared to be somewhat related to loading as shown for synthetic milk wastes in Figure 7. This was most likely due to increased gas activity in the separator at higher loadings.

The odor of the effluent was found to be a function of loading. The intensity of the odor also appeared to increase correspondingly with an increase in volatile acids in the effluent, which would suggest that the odor is

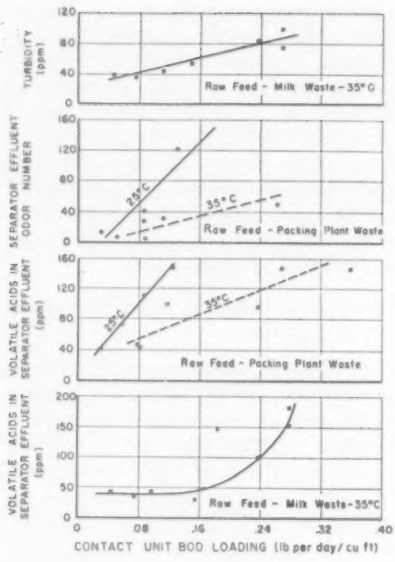
TURBIDITY (ppm)
Raw Feed - Milk Waste - 35°C
SEPARATOR EFFLUENT ODOR NUMBER
25°C
35°C
Raw Feed - Packing Plant Waste
VOLATILE ACIDS IN SEPARATOR EFFLUENT (ppm)
25°C
35°C
Raw Feed - Packing Plant Waste
VOLATILE ACIDS IN SEPARATOR EFFLUENT (ppm)
Raw Feed - Milk Waste - 35°C
CONTACT UNIT BOD LOADING (lb per day/cu ft)

FIGURE 7.—Effect of BOD loading on odor, turbidity, and volatile acids in treated effluent from contact unit.

caused largely by these intermediates. In all cases it was noted that when the process was overloaded or in an upset condition, the volatile acids increased sharply and the effluent developed a very strong obnoxious odor. Some typical results of the relation of contact unit loading to the odor and volatile acids content of the effluent are shown in Figure 7. As a general observation the results of these and previous studies indicate that the effluent from the anaerobic contact process with respect to odor and clarity under less than limiting maximum loading conditions would not constitute a nuisance problem. This statement is substantiated in the case of packing plant wastes by full-scale plant operations.

Gas Production and Analysis

The gas produced from digestion was collected and measured daily in a calibrated gas holder and analyzed. This gas included only that released in the contact unit and did not include the evacuated gas or the gas given off in the separator. No accurate measure of the evacuated gas from the degasifier or the gas given off in the separator was made during these studies.

The law of conservation of matter would indicate that for every pound of volatile matter destroyed a pound of gas should be produced. In general, the gas produced from the anaerobic stabilization of a mixed waste by a mixed culture of organisms produces a gas mixture which is 70 to 90 per cent methane and 10 to 30 per cent carbon dioxide and in some instances a small percentage of other gases. At standard conditions, the specific weight of the gas would be between 0.05 and .0625 lb/cu ft. Therefore, some 16 to 20 cu ft of gas would be expected for every pound of organic matter converted to gas.

The measured gas production during these pilot-plant investigations was consistently low compared with what might be expected (values for the various tests varied from 1.0 to 7.0 cu ft of gas per lb of volatile matter removed). There are a number of reasons for these low gas production figures, but probably the most important was the removal of large quantities of gas in evacuation not included in the gas production figures. One closed system bottle experiment, where it was possible to make an accurate solids and gas balance, indicated that about 14.0 cu ft of gas were produced for each pound of volatile matter destroyed.

Several analyses were made of the gas collected from the pilot plants during each test series. The analysis of the gas did not appear to vary with loading or temperature of operation, but varied somewhat in composition depending on the type of waste being treated. The approximate average analysis of the gas based on the three major constituents for each waste is

tabulated below:

Waste Treated	CH_4 (%)	CO_2 (%)	H_2 (%)
Packing plant	90	10	—
Synthetic milk	85	15	—
Fatty acid	70	18	12

No analysis was made of the gas collected during the pilot-plant test series on wood fiber wastes because of difficulty with the gas analyzer. However, the collected gas burned quite well which suggested a fairly high percentage of methane. In general, the evacuated gas (not analyzed) contains a higher percentage of carbon dioxide since this gas is more soluble than methane. This makes the evacuated gas highly corrosive.

Separation and Concentration Portion of the Process

Since the effectiveness of the anaerobic process as a whole is dependent on maintaining a relatively high concentration and a continuous supply of active biological sludge, it is necessary to provide some method of separating the active sludge from the treated liquor and returning it to the contact unit. In the anaerobic contact process effective separation has been accomplished, as described earlier, by degasification followed by gravity sedimentation. Ancillary investigations, to be discussed in Part II, included several other methods of separation on a batch basis, but all of the continuous flow pilot-plant investigations reported herein provided gravity sedimentation as the separation process.

Gravity Sedimentation

Liquid-solids separation of sludges by gravity has been divided into three zones of separation depending on the concentration of solids. These have been arbitrarily defined as: (a) the discrete particle settling zone where the particles are sufficiently far apart so that the velocity fields of the individual particles do not interfere, (b) the hindered settling zone where the concentration of solids is such that the velocity fields of the individual particles begin to interfere, and (c) the compaction zone where the solid particles are in actual contact and exert an excess pressure or force on the particles below.

The forces governing the liquid-solids separation in the discrete particle settling zone are well established and well understood even in the case of biological and flocculent solids. Unfortunately, the forces governing the separation or thickening process at higher solids concentrations in the hindered settling and compaction zones are not as well established.

Separator Loading and Efficiency Yardsticks

Ancillary investigations and preliminary pilot-plant studies on the gravity separation and concentration of anaerobic sludge indicated that at the high solids concentrations normally used in the anaerobic contact process, discrete particle settling did not play an important role. Thickening or compaction action predominated concurrently with coalescence. For this reason it became apparent that some of the common loading and efficiency yardsticks for settling tanks such as detention period and suspended solids per cent removal would not be as applicable to separation of anaerobic sludge.

In the pilot-plant studies the most significant parameters of separator loading were the surface settling rate expressed as gallons per square foot per day, and the suspended solids applied rate expressed as the pounds of suspended solids applied per square foot per day. As a measure of separator performance the depth of the sludge from the bottom of the separator to the sludge liquid interface appeared to be most significantly related to separator loading.

Effect of Loading on Separator Performance

The results on the effect of separator loading on separator performance obtained during the bulk of the pilot-plant tests on the anaerobic contact process are not well correlated and are somewhat difficult to evaluate. The reason the sludge did not behave in the same way each time even under the same separator loading conditions is not completely understood. Some of this variation might have been influenced by scale effects on the small pilot-plant units and the difficulty of establishing exact equilibrium conditions. Probably more significant is the fact that the compacting character of the sludge varied considerably during some of the tests and was apparently very sensitive to conditions which were either being tested or could not be controlled in the pilot plants. However, the results on the effect of loading on separator performance indicate

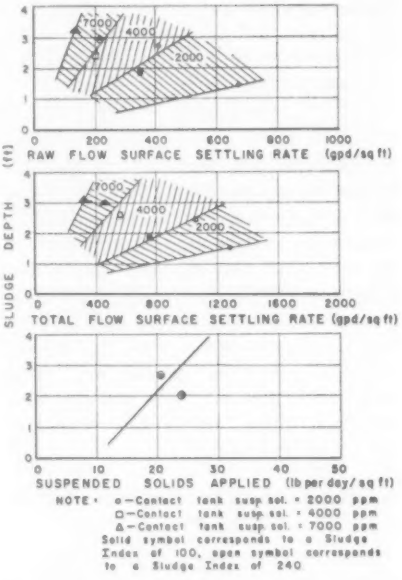
7000
4000
2000
RAW FLOW SURFACE SETTLING RATE (gpd/sq ft)
SLUDGE DEPTH (ft)
TOTAL FLOW SURFACE SETTLING RATE (gpd/sq ft)
SUSPENDED SOLIDS APPLIED (lb per day/ sq ft)
NOTE: o—Contact tank susp. sol. = 2000 ppm
□—Contact tank susp. sol. = 4000 ppm
Δ—Contact tank susp. sol. = 7000 ppm
Solid symbol corresponds to a Sludge Index of 100, open symbol corresponds to a Sludge Index of 240

FIGURE 9.—Effect of separator loading on total sludge depth in treatment of milk waste.

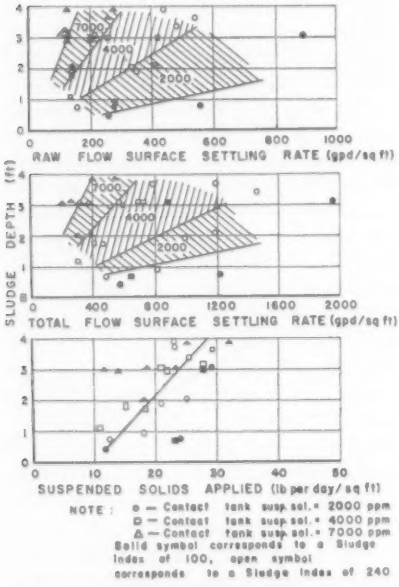
7000
4000
2000
RAW FLOW SURFACE SETTLING RATE (gpd/sq ft)
SLUDGE DEPTH (ft)
TOTAL FLOW SURFACE SETTLING RATE (gpd/sq ft)
SUSPENDED SOLIDS APPLIED (lb per day/ sq ft)
NOTE: o — Contact tank susp. sol. = 2000 ppm
□ — Contact tank susp. sol. = 4000 ppm
Δ — Contact tank susp. sol. = 7000 ppm
Solid symbol corresponds to a Sludge Index of 100, open symbol corresponds to a Sludge Index of 240

FIGURE 8.—Effect of separator loading on total sludge depth in treatment of milk waste.

some interesting trends especially if considered in the light of the ancillary studies on gravity separation.

A series of special pilot-plant separation studies were conducted during the tests of Series 6 treating synthetic milk waste at an operating temperature of 25°C. These tests were carried out at a constant contact unit loading of about 0.07 lb per day/cu ft and were designed specifically to determine the effect of separator loading on sludge depth. The effects of surface settling rate and solids applied rate on sludge depth for these tests are shown in Figures 8 and 9. At first glance it appears that there is little correlation of the raw flow or total flow surface settling rate with the total sludge depth. However, the effect of the suspended solids applied rate on sludge depth does indicate a definite trend. This would tend to show that the solids applied rate is more significant than the volumetric rate in predicting sep-

arator performance in terms of sludge depth. If the data on surface settling rate are separated in accordance with the suspended solids concentration as shown by the different symbols, the data generally fall into three separate zones as indicated and show quite clearly the effect of solids concentration on maximum permissible surface settling rate.

Unfortunately, the compacting characteristics of the sludge as measured by the Mohlman sludge index varied considerably during these tests and undoubtedly caused some of the scatter in the results. The effect of this variable was not measured accurately since only two sludge volume indices were taken during the period of the tests. The data for these tests have been grouped and averaged in Figure 9 to show the effect of the sludge index. As would be expected in all cases under equal loading conditions, the sludge depth is greater for a higher sludge index.

During the pilot-plant tests of Series 3, 4, 5, and 6 which were designed to study the contact unit, the operation of the pilot plants with respect to separation was quite similar. The separation was carried out in each case using vacuum degasification and gravity settling in a cylindrical tube four feet deep. Since the tests were designed to study the contact unit, the separation portion of the process was operated so as to prevent the loss of solids in the effluent. Thus, during the individual tests the separator loading rate was adjusted to maintain a sludge level somewhat below overflow level. During some of the tests the settling and compacting character of the sludge varied due to changes in loading and other operating conditions. The contact unit loading was the main variable during these test series and ranged from 0.02 to 0.33 lb per day/cu ft for the various tests. The data on separation for these tests are quite scattered and difficult to analyze.

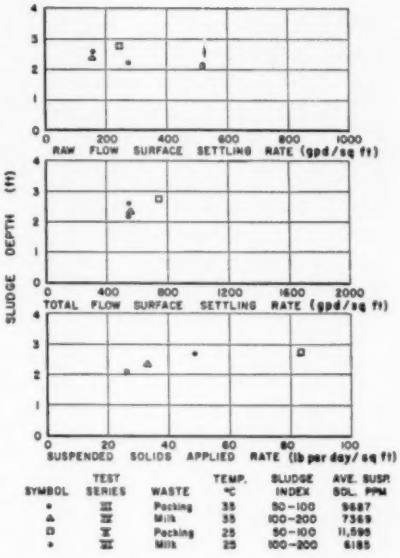
SLUDGE DEPTH (ft)
RAW FLOW SURFACE SETTLING RATE (gpd/sq ft)
TOTAL FLOW SURFACE SETTLING RATE (gpd/sq ft)
SUSPENDED SOLIDS APPLIED RATE (lb per day/sq ft)
SYMBOL | TEST SERIES | WASTE | TEMP. °C | SLUDGE INDEX | AVE. SUSP. SOL. PPM
• | III | Packing | 35 | 50–100 | 9687
▲ | IV | Milk | 35 | 100–200 | 7349
□ | V | Packing | 25 | 50–100 | 11,595
▪ | VI | Milk | 25 | 100–200 | 6185

FIGURE 10.—Effect of separator loadings on total sludge depth for test series 3, 4, 5, and 6.

However, if the results on the effect of separator loading on sludge depth are averaged for each test series as shown in Figure 10, some general conclusions can be drawn.

It is apparent that the average separator loading in terms of the surface settling rate and the sludge depth carried in the separator were about the same for all of the test series. For this reason these results do not describe a significant trend for the effect of surface settling rate on sludge depth. It is significant to note, however, that the average solids applied rate for approximately the same sludge depth (2.5 ft) varied over quite a wide range (25 to 85 lb per day/sq ft) for these tests. In a large scale installation where the sludge depth could be carried at a higher level, this loading range would be correspondingly increased. It is clear from these data that the effect of separator loading on sludge depth is materially affected by the character of the sludge as measured by the sludge

index. The character of the sludge with respect to separation and concentration appears to be sensitive to a number of operating conditions, including the type of raw feed and the contact unit loading. For this reason the maximum separator loadings for efficient operation appear to be somewhat peculiar for each individual case. At the present time separator design and operation yardsticks can be established from pilot-plant studies for any particular case but further work is necessary to determine the specific factors which affect concentrating ability and bulking characteristics of anaerobic sludges.

Effect of Degasification in Separation

Production of gas by the biological action of anaerobic sludges tends to cause some of the solids to be gas-lifted. Thus, the solids of an active sludge separate into a floating layer and a settled layer. The removal of the gas bubbles from the solids by vacuum degasification at 15 in. Hg prior to separation has been used in the pilot plants as a method of eliminating, or at least reducing, floating solids. On a batch basis this action can be demonstrated readily.

An attempt was made to demonstrate the effect of degasification in the performance of the separation process in the continuous flow pilot plants. Several tests were carried out using parallel degasified and non-degasified separation. It is difficult to evaluate numerically the effect of degasification based on the results of these tests since the effect is apparently influenced to a large extent by loading and gas activity in the sludge. Also, the failure of the process due to floating sludge was somewhat an all-or-none effect and could not be traced as gradual change. In general, observations made during these tests indicate that at low contact unit loadings, positive settling separation could possibly be achieved without degasification. However, at higher contact unit loadings when gas activity is high, degasification was found to be necessary to prevent extensive gas lifting and loss of floating solids.

Rapid Adsorption-Sludge Regeneration Process

There are a number of modifications of the basic anaerobic contact process from the standpoint of flow diagram and arrangement and type of units which can be developed. One such modification which seemed to be worthy of investigation for the treatment of relatively cool wastes has been investigated on a limited basis during this program and has been termed the rapid adsorption-sludge process.

Description of the Process

This modification of the anaerobic contact process is comparable to the adsorption modification of the aerobic activated sludge process. The flow diagram includes an adsorption unit in addition to a contact unit, degasifier unit, and separation unit arranged as

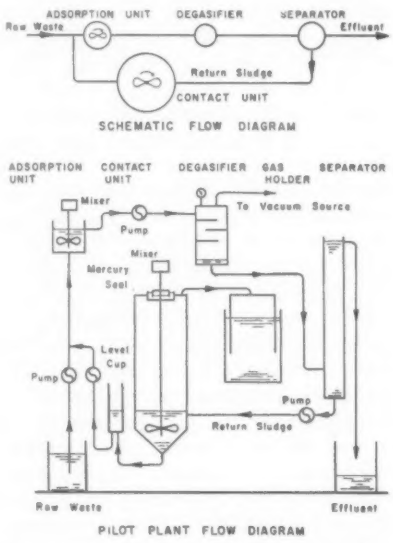

FIGURE 11.—Schematic and pilot-plant flow diagrams for rapid adsorption-sludge regeneration process.

TABLE IX.—Summary of Contact Unit Performance in Rapid Adsorption Process Treating Milk Waste—Test Series 8 Operated at 35°C

Test No. (1957)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)		Det. Period in Contact Unit for Return Sludge Flow (hr)	Removal (per cent)	
			Contact Unit		Total Volume						
	Temp. (°C)	Susp. Solids (ppm)	BOD	COD	BOD	COD	BOD	COD		BOD	COD
3 (June 24–July 5)	33.7	7,175	0.100	0.132	0.065	0.085	6.89	5.26	5.71	91.2	84.0
4 (July 8–31)	34.5	7,912	0.138	0.197	0.088	0.128	5.61	3.86	7.36	81.3	78.1
5 (Aug. 1–9)	34.1	8,143	0.157	0.225	0.094	0.135	5.41	3.76	7.62	78.8	77.7
6 (Aug. 12–15)	33.5	7,249	0.103	0.202	0.065	0.120	7.50	3.76	8.50	75.0	80.3
10 (Oct. 15–22)	34.5	9,216	0.1006	0.230	0.0578	0.1290	9.40	4.58	6.04	88.1	80.8
11 (Oct. 28–Nov. 8)	34.6	6,658	0.1190	0.177	0.0700	0.0988	6.04	4.56	12.87	81.0	77.2
12 (Nov. 12–21)	34.4	4,971	0.1051	0.182	0.0662	0.1110	4.24	2.82	16.1	74.1	72.4

shown in the schematic flow diagram in Figure 11. In this process the raw waste is mixed with active anaerobic sludge in an unheated adsorption unit for a relatively short time. This mixture is then degasified and allowed to separate in a gravity separation unit in the same manner as in the anaerobic contact process. The effluent is withdrawn from the top of the separator and the sludge which settles to the bottom is returned to a heated contact unit where it is allowed to regenerate its adsorptive capacity before being reused in the adsorption unit. To adapt this from the contact process, it was only necessary to add an adsorption unit and rearrange the units as shown in the pilot-plant flow diagram in Figure 11.

This modification separates the two principal actions of adsorption and stabilization into separate units. Although there may be other advantages, one obvious advantage of this process is that only the sludge returned to the contact unit need be heated, and on this basis, the thermal requirements of this modification would be somewhat less than those for the anaerobic contact process assuming the organisms were capable of adjustment for a several-hour period to a temperature appreciably lower than that of the contact tank. This element is discussed later in this report. A series of preliminary tests on synthetic milk waste and domestic sewage were carried out using this flow diagram.

Synthetic Milk Wastes

Pilot-plant tests on the rapid adsorption of milk waste were carried out primarily to compare the performance of this process with the standard anaerobic process. A summary of the operation and removal data for these tests designated as Series 7 is shown in Table IX. The effects of loading on BOD removal for these tests shown in Figure 12 are somewhat scattered over a narrow loading range. To evaluate even an approximate trend based on these limited data is uncertain. However, the data do indicate that for this type of waste, and at the concentration at which it was fed, this process is capable of removing about 80 per cent of the BOD load applied to it at a contact unit loading of 0.13 lb per

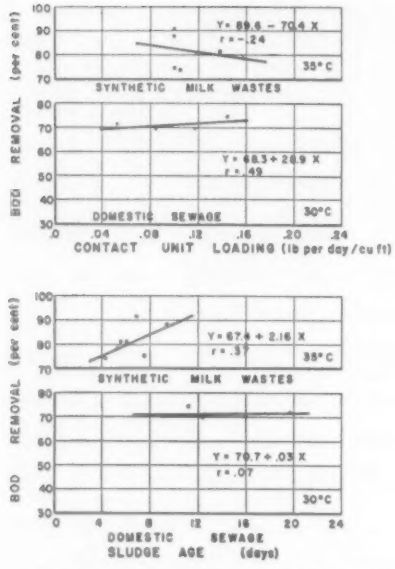

FIGURE 12.—Effect of BOD loading and sludge age on the performance of the rapid adsorption process.

day/cu ft or a sludge age of five days. This is compared to a removal of about 95 per cent for the anaerobic contact process under similar loading conditions and operating temperature.

It would seem logical to expect that the degree of removal of organic matter by this process would be a function of the time of contact between the active sludge particles and the waste. In this respect the question arises as to the effect of the relative detention times in the adsorption and separation phases compared to that in the contact phase on the process performance since an appreciable temperature difference can exist in the two phases.

The effects of adsorption unit detention period in terms of raw flow and total flow and the contact unit detention time in terms of the return sludge flow on BOD removal for milk waste are shown plotted as solid points in Figure 13. Over the range of detention periods used in these tests, there does not appear to be any significant

TABLE X.—Summary of Contact Unit Performance in Rapid Adsorption Process Treating Domestic Sewage—Test Series 9 Operated at 35° and 30°C

Test No. (1958)	Contact Unit		Loading (lb per day/cu ft)				Sludge Age (days)		Det. Period in Contact Unit (hr)		Removal (per cent)			
			Contact Unit		Total Volume									
	Temp. (°C)	Susp. Solids (ppm)	BOD	COD	BOD	COD	BOD	COD	Raw Flow	Return Sludge Flow	BOD	COD	Tot. Vol. Solids	Susp. Solids
4 (Feb. 6–21)	29.5	11,009	0.052	0.150	0.035	0.102	19.70	7.18	6.95	13.90	71.4	61.8	42.6	71.4
5 (Feb. 22–28)	29.5	8,757	0.084	0.187	0.056	0.125	12.50	5.62	3.94	7.76	69.6	49.0	36.7	47.4
6 (Mar. 1–8)	29.5	9,528	0.097	0.230	0.050	0.120	12.65	5.30	3.86	7.20	70.5	56.0	44.6	61.5
7 (Mar. 10–14)	29.5	9,096	0.144	0.341	0.059	0.140	11.20	4.72	2.53	2.45	74.5	57.7	29.9	52.0
8 (Mar. 17–28)	29.5	7,480	0.117	0.280	0.054	0.129	9.12	3.83	3.07	2.30	69.7	54.6	37.2	34.7

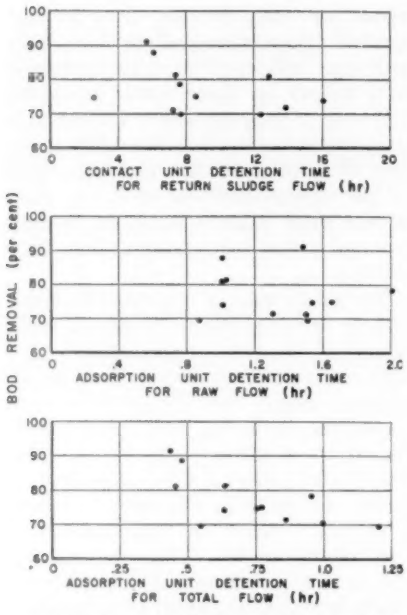
BOD REMOVAL (per cent)
CONTACT UNIT DETENTION TIME FOR RETURN SLUDGE FLOW (hr)
ADSORPTION UNIT DETENTION TIME FOR RAW FLOW (hr)
ADSORPTION UNIT DETENTION TIME FOR TOTAL FLOW (hr)

FIGURE 13.—Effect of contact and adsorption unit detention times on BOD removal in the rapid adsorption process.

correlation. The reason for this, as will be shown later, is that the initial uptake of organic matter by anaerobic sludge is quite rapid and reaches equilibrium in most cases in less than one-half hour of reaction time.

Domestic Sewage

A summary of the pilot-plant operation and removal data for the rapid adsorption of domestic sewage designated as Series 9 is shown in Table X. The effects of contact unit loading and detention period on BOD removal for this waste are also shown in Figures 12 and 13. In this instance the contact unit was maintained at a temperature of 30°C and the return sludge was reduced to as low as 25 per cent of the raw flow in order to reduce the thermal requirements of the process. It is apparent in this case that the BOD removal remained constant at 70 to 75 per cent over the range of loading and operating conditions tested. Several tests were carried out using an operating temperature of 35°C. During one of these tests at a contact unit loading in excess of 0.17 lb per day/cu ft, the process failed completely indicating the existence of a maximum limiting load beyond which the process becomes upset.

Accelator Anaerobic Studies

During the research program a number of preliminary tests were carried out using a 48-gal model of the Accelator * for the anaerobic treatment of milk waste. Tests were carried out using synthetic milk waste as the raw feed with the unit maintained at room temperature (22° to 27°C). It was necessary to provide for a secondary settling unit with about a 1-hr detention period in order to prevent the loss of floating solids. This model arrangement was operated for a period of four months using digesting sewage sludge as the initial inoculant. In general, the results of these preliminary tests indicate that this arrangement was capable of removing 85 per cent of the COD of a milk waste containing 500 ppm of COD at a detention period of about 24 hr and an organic loading of 0.04 lb per day/cu ft. This loading was selected on the basis of limited pump capacity and is not necessarily a limiting load. Further work is underway using a different model of the same general unit.

Economics of the Process

Economic Analysis of Thermal Requirements

The factor of most importance in a decision on the application of the process in a particular situation is the thermal requirement. Obviously, a warm, concentrated waste from a vola-

* Furnished by Infilco, Inc., Tucson, Ariz.

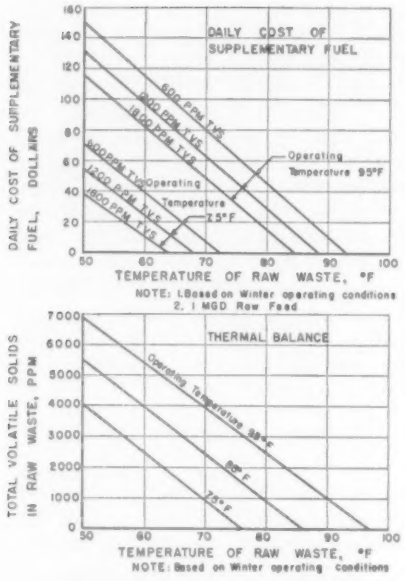

FIGURE 14.—Thermal requirements of the anaerobic contact process for various temperatures.

tile solids standpoint can be more economically treated by this process than a colder dilute waste. Other elements such as system operating temperatures, thermal efficiencies, fuel costs, climatic conditions, percentage of return sludge, and flow diagram employed affect the economic balance. Summarily it can be stated that the thermal consideration will usually be the controlling factor in the determination of the most economical method of treatment.

Conventional Anaerobic Process

The detailed bases for calculation of the thermal balances in this process are not presented. The major decisions and assumptions employed in the calculations of Figure 14 which summarizes the economics of the problem are the following: (a) gross calorific value of gas of 830 Btu per cubic foot, (b) operations under winter conditions at a latitude north of 45° with mean air temperatures of 0°F and ground temperatures of 40°F, (c) 72 per cent efficiency in heat exchange and boilers or other direct methods, (d) cost of supplementary fuel at natural gas price of $0.35 per 1,000 cubic feet of 1,000 gross Btu per cubic foot of gas, (e) destruction of 60 per cent of the total volatile solids in the incoming wastes and resultant gas production.

An inspection of Figure 14 shows clearly the importance of the thermal situation in cost comparisons. The upper chart shows the daily cost of supplementary fuel for various raw wastes and operating temperatures and for wastes of different strengths. The lower chart shows similar data but in terms of conditions necessary to effect a thermal balance (no supplementary fuel requirements). The importance of warm or concentrated organic raw wastes is clearly apparent from the two charts and would be equally valid, within limitations, regardless of refinements in assumptions in the basic calculations.

Rapid Adsorption Process

Among other flow diagrams which could be conceived is that described as the rapid adsorption-sludge regeneration process.

This particular flow diagram was originally considered as a result of 1952 suggestions by R. Knutson, Chemist of the Austin city sewage treatment plant. It was subsequently learned that some variations of the diagram may be included by claims in the Mortenson patent.*

Thermal balance calculations for this flow diagram are shown in Figure 15, the upper portion for 95°F, and the lower portion for 85°F in the contact unit. As indicated from a comparison of Figures 1 and 11, the basic thermal difference between the two processes is that the conventional proc-

* U. S. Patent 2,661,332 (Dec. 1, 1953).

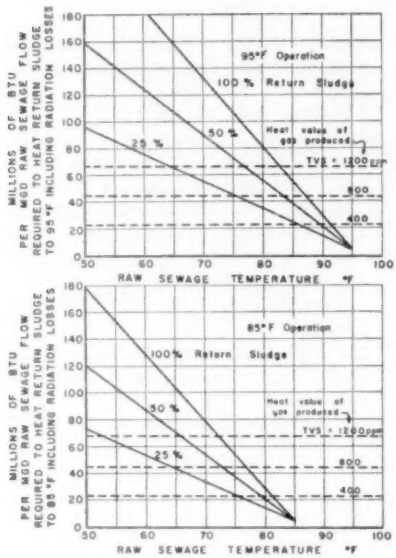
MILLIONS OF BTU PER MIL RAW SEWAGE FLOW REQUIRED TO HEAT RETURN SLUDGE TO 95 °F INCLUDING RADIATION LOSSES
95°F Operation
100 % Return Sludge
50 %
25 %
Heat value of gas produced
TVS = 1200 ppm
800
400
RAW SEWAGE TEMPERATURE °F
MILLIONS OF BTU PER MIL RAW SEWAGE FLOW REQUIRED TO HEAT RETURN SLUDGE TO 85 °F INCLUDING RADIATION LOSSES
85°F Operation
100% Return Sludge
50 %
25 %
Heat value of gas produced
TVS = 1200 ppm
800
400
RAW SEWAGE TEMPERATURE °F

FIGURE 15.—Thermal requirements of rapid adsorption process for 95°F and 85°F operation.

ess generally discussed herein involved approximately uniform operating temperatures assumed at 95°F in the contact and separation units.

The rapid adsorption process has an apparent but possibly not real thermal advantage over the conventional process described. Since only the contact (regeneration) tank temperature is maintained at the high temperature (95°F) the anaerobic culture developed at that temperature is mixed with the incoming waste at a lower temperature, the mixture being subjected to a 1- to 3-hr exposure at the weighted reduced temperature. At a one-to-one mixture of return sludge at 95°F and an incoming waste at 65°F, the organisms in the sludge are subjected to a 15°F decrease in temperature in the separation phase for a period of as much as one-half the time in the system. This flow diagram has its apparent greatest thermal advantage when raw waste temperatures and concentrations are low, but is reduced as raw waste temperatures approach contact tank temperatures and concentrations increase.

The effect of such rapid changes in environment under continuous pilot-plant operations should be studied further. These investigations confirm the importance of narrow range changes in environmental conditions.

The basis of calculation in plotting Figure 15 is similar to that in Figure 14 except that because of lower indicated performance as a result of experimentation, a volatile solids removal of 50 per cent has been assumed as a basis of gas production instead of the 60 per cent value for the basic flow diagram.

Effects of Suspended Solids Concentration

It has been shown that, within limits, there is an advantage to increasing the concentration of the solids in the contact portion. However, solids concentration, by creating higher loadings on the separation process, make necessary equipment size increases.

Thus, an economic balance between the costs of the contact and the separation processes becomes necessary. The final determination for a particular situation would be affected by many factors. For the conditions studied it is indicated that under conditions of gravity sedimentation, suspended solids concentration in the contact unit to between 10,000 and 15,000 ppm is economical. Other methods of sludge concentration, including wicketing and weighting additives, flotation, wet cycloning, and centrifuging, could change this indicated advantage point and should be investigated.

Economics of Raw Flow Equalization

It has been indicated that the anaerobic process consists of two separate unit operations, the first including physical adsorption and biological reaction, and the second utilizing separation of clarified effluent and return of

settled and compacted solids to the influent. The contact process has been shown to have a reasonable degree of flexibility in adjusting to variations in load. The separation process being affected principally by physical actions, is influenced directly by volumetric changes in raw feed, assuming a constant level in the contact tank. Therefore, if any adverse effect of variations in feed to the entering contact process is neglected, the economic problem becomes one of balancing the capital and operating costs of direct handling of the flow variations in the plant against equalization of flow by the use of storage tanks.

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3. Steffen, A. J., "Full-Scale Modified Digestion of Meat Packing Wastes." THIS JOURNAL, **27**, 12, 1364 (Dec. 1955).
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AMERICAN WATER WORKS ASSOCIATION OFFICERS

At the recent American Water Works Association annual meeting of the Board of Directors the following schedule of nominations for the coming year was made:

President: Lauren W. Grayson, Chief Engineer and General Manager, Public Service Department, Glendale, Calif.

Vice-President: C. F. Wertz, Director of the Department of Water and Sewers, Miami, Fla.

Treasurer: William J. Orchard, General Manager, retired, Wallace and Tiernan Inc., Belleville, N. J.

TEACHING OPPORTUNITY

Cornell University announces the availability of a teaching assistantship in the School of Civil Engineering to candidates for advanced degrees in Sanitary Engineering.

The position requires 30 hours per week of undergraduate Sanitary Engineering instruction. The stipend is approximately $3,300, not including university fees and one-half tuition. One-half residence unit per term is received.

For further information contact Charles D. Gates, Head, Department of Sanitary Engineering, School of Civil Engineering, Cornell University, Ithaca, N. Y.

TREATMENT OF WASTES FROM TALL OIL REFINING *

By B. W. Dickerson, W. T. Laffey, and R. O. McNeil

Hercules Powder Company, Wilmington, Del.

The Franklin, Va., plant of Hercules Powder Company is located on the Nottoway River in the area of Delaware Park. The plant, which went into production in June 1956, fractionates crude tall oil to obtain rosins and fatty acids. Tall oil, which derives its name from tallolja (which means oil of pine in Swedish) is a regular by-product of kraft pulp manufacture and is obtained from neighboring pulp mills. Rosin obtained from tall oil is used in paper making, varnishes, printing inks, and chemical intermediates, while fatty acids are used in the manufacture of soaps, rubber, lubricants, paint, flotation agents, and protective coatings. At Franklin, the industrial wastes consist of process condensate from distillation, primary purification wastes, tank car washings, and floor washings. Sanitary wastes from some fifty employees are collected in a sanitary sewerage system, comminuted, and pumped directly to the waste treatment plant.

In December 1954, Hercules Powder Company announced its intention of entering the field of processing crude tall oil. Completion of the plant was scheduled for the first half of 1956. With no experience in treating tall oil wastes and no references in the literature, the company was faced with the problem of securing design data, designing the plant, and completing construction within a period of 12 to 18 months. A semi-plant was in operation in one of Hercules' southern plants and a very limited amount of waste water was available for experimentation. Although unknown at this time, further experimental work was to be undertaken at the Hercules Research Center and additional wastes were to be available. However, the quantity was limited and certainly less than desired for adequate waste treatment pilot-plant studies.

Pilot-Plant Studies

Chemical Treatment

For the initial studies, there were available two barrels of waste from the two phases of operation. The first batch, designated as Waste A, had a heavy layer of floating oil and the bottom liquid had a cloudy, greasy appearance. An analysis of the mixture of the two layers showed over 5,000 mg/l of chloroform-soluble oil and 19,000 mg/l of BOD. After the layers were allowed to separate by gravity, analysis of the bottom layer showed a reduction to about 500 mg/l soluble oil and less than 3,000 mg/l BOD. The volatile acids in the mixture were similarly reduced from about 1,000 to 200 mg/l. The second batch, referred to as Waste B, was similar in appearance but the oil, BOD, and volatile acids concentrations were about one-third of those found in Waste A. Although most of the oil could be separated by gravity, a considerable amount remained in emulsion. It was felt at this time that it would be necessary to remove these emulsified oils, not only to reduce the organic load to the waste treatment facilities, but also to prevent an oil-film barrier over the biologic slimes

* Presented at the 13th Industrial Waste Conf., Purdue University; Lafayette, Ind.; May 5–7, 1958.

TABLE I.—Typical Waste Analyses

Item	Waste					
	A[a]	B[b]	C[c]	C_1[d]	D[e]	D_1[f]
Total solids (mg/l)	5,560	2,100	3,920	1,470	860	412
Total volatile solids (mg/l)	5,540	2,079	3,900	538	820	304
Suspended solids (mg/l)	5,270	1,985	3,550	104	19	8
Volatile suspended solids (mg/l)	5,260	1,975	3,540	94	13	5
pH	3.7	3.7	3.7	8.3	5.0	8.8
Chloroform solubles (mg/l)	5,730	1,390	3,450	160	300	120
Volatile acids, as acetic (mg/l)	1,030	70	540	167	130	120
COD (mg/l)	9,200	3,920	7,050	1,600	2,450	2,100
BOD-5 (mg/l)	19,000	5,500	11,000	1,100	1,160	1,100
k, rate constant (per day)	—	—	—	0.16	—	0.14
L, first-stage BOD (mg/l)	—	—	—	1,300	—	1,380

[a] Waste from first phase of operations.
[b] Waste from second phase of operations.
[c] Mixture of A and B.
[d] Waste C, de-emulsified.
[e] Waste from Research Center.
[f] Waste D, de-emulsified.

that could prevent oxygen transfer or cause bacteriostatic conditions. A number of de-emulsification tests were run by adjusting the pH to various levels using lime, caustic soda, soda ash, and ammonia. They were used separately and in various combinations. In addition, coagulants, such as alum, calcium chloride, ferric sulfate, and others, were tested in various combinations with the alkalies.

With the addition of 1,000 mg/l calcium chloride, followed by sufficient caustic soda, soda ash, or ammonia, a sticky, slow-settling floc was formed. The supernatant was light brown in color and very clear. The use of lime, alum, ferric chloride, and ferric sulfate resulted in very poor or no floc formation. When the pH was adjusted to 9.0 prior to the addition of the calcium chloride, a fairly dense, good-settling floc was formed. The supernatant was clear with a lighter brown color. The results of the de-emulsification tests were similar on Wastes A and B and on a mixture of the two, Waste C. About 95 per cent of the precipitate settled in 30 min. Tests indicated that the sludge could be filtered at a rate of over 1 gpm/sq ft with 20 to 24 in. of vacuum. The tests also showed that one pound of filtered sludge would be produced from 2,500 gal of waste. The solids content of the filtered sludge was 25 per cent. Analyses of Wastes A, B, and C and the supernatant after de-emulsification of Waste C are shown in Table I.

Trickling Filter Studies

All additional bacteriological work was done using Waste C. The need for chemical treatment was obvious after biological studies were made. Without de-emulsification, Waste C was toxic to sewage bacteria even after dilution with river water to a 10 per cent concentration. Adjustment of the pH to 8.0 and dilution to 50 per cent indicated a bacteriostatic condition and the oily emulsion tended to coat the filter stone. The work was started by seeding two filters with settled domestic sewage and adapting the wastes to these units. One filter operated as a single pass filter and the waste, diluted to 50 per cent, was applied at a rate slightly exceeding 23 gpd/sq ft. Although the BOD was reduced by 83 per cent, the effluent

contained no dissolved oxygen and the oxygen demand was high. In view of this it was decided to concentrate on a filter utilizing recirculation. The effluent from the second filter was settled for about 30 min, aerated for an additional 30 min, mixed with the incoming waste, and re-applied to the filter. The ratio of recirculated liquid to raw waste was 5:1 and the BOD loading was increased to 16.5 lb per day/1,000 cu ft and applied at a rate of 152 gpd/sq ft. The BOD of the diluted waste was reduced from 470 to 24 mg/l, a reduction of 95 per cent. As the dilution water was gradually reduced to zero a large amount of frothing took place. In an attempt to control frothing, the recirculation ratio was decreased from 5:1 to 3:1. In a few days the system became acclimatized and, after a temporary drop, BOD removals gradually increased to about 95 per cent again and no frothing recurred.

At no time was there any disagreeable odor from the filter. The effluent was completely stable and showed no evidence of odor or further decomposition even after standing 15 days at room temperature. The effluent was quite high in color, low in suspended solids, and very clear. Analyses of the waste, before and after treatment, are shown in Table II. One- to 10-day BOD tests were made on composite samples and it was found that the first-stage BOD was also reduced by about 95 per cent. The BOD curves are shown in Figure 1. Nitrification was evident at about eight days for the influent and at five days for the effluent. In actual practice, it would be prudent to reduce the phosphorus and nitrogen nutrients to minimize algal growths at the outfall.

Activated Sludge Studies

Aeration studies looked attractive, but there was a reluctance to consider seriously activated sludge treatment here. The principal advantages were obvious—a high degree of treatment, a smaller area required, and a lower investment.

Earlier opinions nothwithstanding, there were signs that a closer look at activated sludge treatment was warranted. Warburg respirometer studies under nearly all variables indicated: treatment equal to or better than trickling filter treatment could be obtained; nutritional requirements should be equal; and pH requirements certainly should be no more critical. If an excess of sludge could be made available to absorb sudden increases in load, and if the plant could be designed to operate with a minimum of supervision, then the principal objections would be eliminated and the advantages would outweigh the disadvantages. The only trouble at this point was that the waste samples were so depleted that an adequate study could not be made. With the small amount of wastes remaining, runs were made for a few days that led to the conclusion that an activated sludge plant with 24 to 30 hr aeration could produce the same degree of treatment as a trickling filter.

Realizing the advantages of an activated sludge plant, but not having

TABLE II.—Typical Analyses of Treated Wastes from Tall Oil Processing

Constituent	Trickling Filter Treatment			Activated Sludge Treatment		
	Untreated	Treated	Removal (%)	Untreated	Treated	Removal (%)
Total volatile solids (mg/l)	538	334	38	820	240	72
Chloroform solubles (mg/l)	160	48	70	300	60	80
BOD-5 (mg/l)	1,100	42	96	1,200	100	92

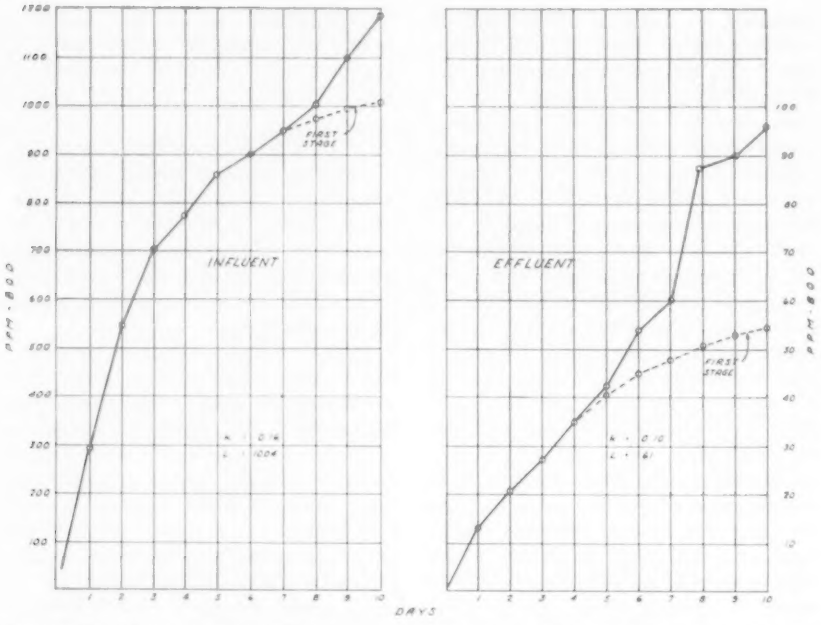

FIGURE 1.—Typical 10-day BOD progression of de-emulsified Waste C before and after laboratory trickling-filter treatment.

the information necessary to design one and being reluctant to be anything less than conservative, it was a welcome relief to be informed that a semi-plant would be run for a short period of time at the Hercules Research Center. A few more drums of the waste products were made available and the process engineers assured that this latest waste would more closely resemble the actual operating waste. This new waste, referred to as Waste D, closely resembled the de-emulsified waste mixture of the previous samples. De-emulsification studies indicated that alkali and calcium chloride additions had very little effect on the waste strength and certainly the costs would not be justified for the small reductions obtained.

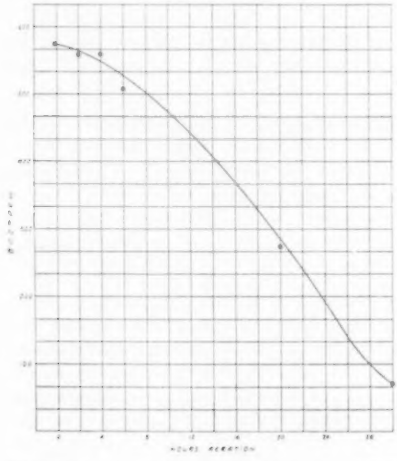

FIGURE 2.—Effect of aeration on BOD removal.

Warburg studies showed substantial agreement with the chemically treated original wastes so aeration studies were begun. Samples were removed at 2 hr intervals for 6 hr and at 24 and 30 hr. Figure 2 shows the per cent BOD removal for the different retention times. Table II shows

results obtained with both trickling filters and activated sludge.

Waste Plant Design

General

A flow sheet based on the final design is shown in Figure 3. The design was based on an anticipated flow of approximately 0.1 mgd with a BOD concentration of about 1,200 mg/l. The primary purification wastes and process condensate flow by gravity to the wet well. The floor washings and car washings are pumped to the wet well. All sanitary sewage is collected in a separate system and flows to a separate lift station where it is comminuted before being pumped directly to the activated sludge aeration tank. The industrial waste is pumped from the wet well to an oil separation chamber where the floating oils are skimmed off and collected for burning. The underflow passes to the first-stage mixing chamber where ammonia and soda ash are added, then to the second mixing chamber where calcium chloride and phosphate are added. From there, the wastes pass through a Parshall flume, thence to the settling basins where the solids are settled. From here, it is pumped to the activated sludge aeration tank, then proceeds by gravity to the final settling tank. After settling, the effluent is mixed with uncontaminated cooling water and flows through the outfall ditch to the river. The sludge is pumped to the sludge reaeration tank and a portion of the clarified effluent is returned to the activated sludge tank.

Lift Pumps Level-control Valve

Process wastes are collected in the wet well and pumped to the oil separator by vertical self-priming pumps. The suction lift is about 8 ft. The pumps were designed to handle not only the wastes at a temperature of

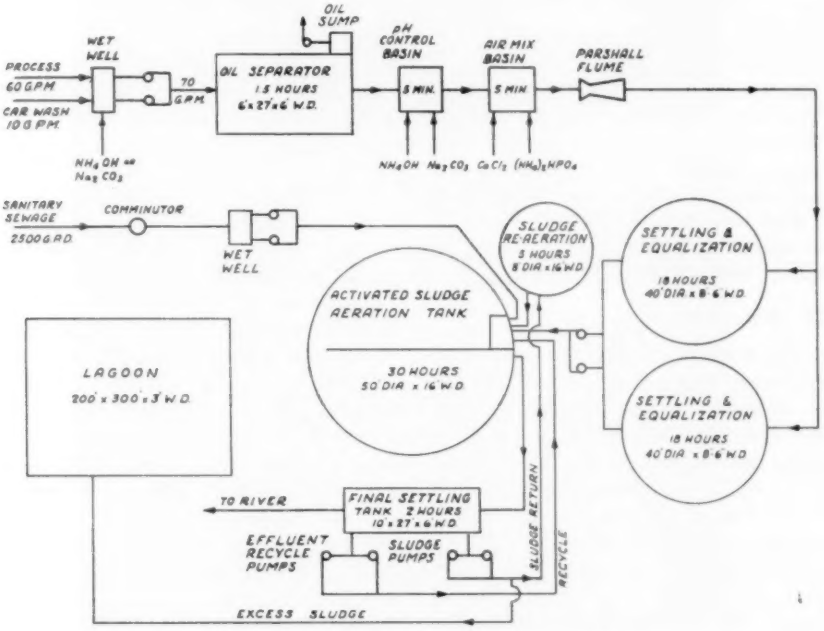

FIGURE 3.—Flowsheet of waste treatment plant.

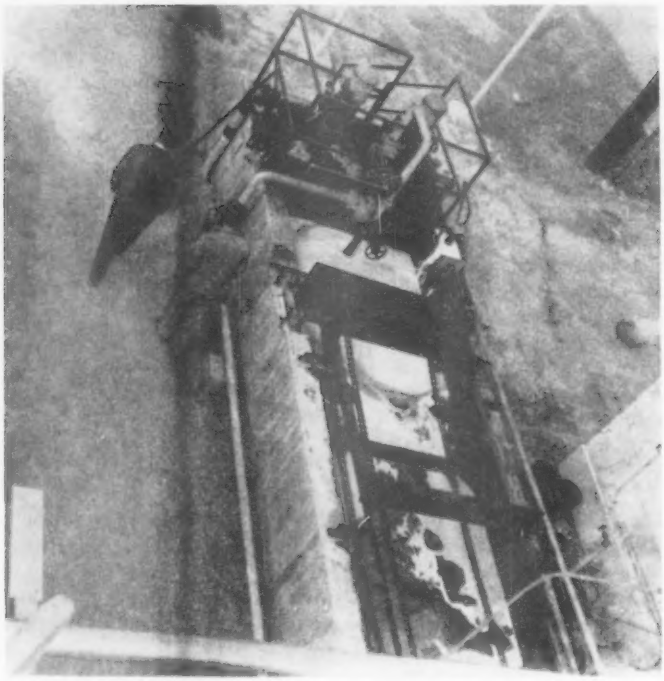

FIGURE 4.—Wet well and oil separator.

140°F, but to aspirate 1.5 cfm of air. The valve on the discharge side of the pumps controls the level in the pump sump and is regulated pneumatically by a controller actuated by a float valve in the wet well. Soda ash is added at the wet well to increase the pH to about 6 or 7.

Oil Separator

The wastes then pass through the oil separator which has a retention time of 90 min. The free oil floats and is conveyed by flights up an inclined ramp into a trough and then passes to an oil sump. Periodically, the accumulated oil is pumped into drums and is removed to be burned in the boiler furnaces together with light ends and pitch from process operations. The subnatant then passes under a baffle and into the first-stage mixing chamber. The wet well and oil separator are shown in Figure 4.

Mixing Chambers and Chemical Feed Pumps

In the first-stage mixing chamber, the pH is increased to the point required for de-emulsification. Aqueous ammonia is fed primarily for the nitrogen required for bacterial cell metabolism and, secondarily, for the alkalinity. A pH controller in the chamber controls the feed of soda ash. A propeller-type mixer is installed here. In the second-stage chamber, a phosphorus salt is added for nutrient, and calcium chloride is added for precipitation of emulsified oils. To prevent the floc from breaking into fine particles, a gentle air mix is used, the air is obtained from the blowers furnishing air for biological treat-

ment. A single carborundum tube distributes the air.

Parshall Flume and Chemical Pumps

The Parshall flume is used not only for flow measurement but for control of the chemical feed pumps. The pumps are all connected to a single motor and, as the speed of the motor changes in proportion to the flow, the chemical feed rates are likewise changed. However, the soda ash required for pH adjustment is not always a direct function of the flow and a separate air motor, actuated by the pH controller, adjusts the stroke of that pump so that the proper amount of soda ash is fed.

Primary Settling and Equalizing Tanks

The chemically treated wastes flow to two settling basins providing a detention of 18 hr in each tank. No sludge collection equipment was installed but when necessary the solids are pumped to a tank truck and hauled to a burial site. One unit is used at a time. Piping is arranged so that the tanks may operate either in series or parallel.

Activated Sludge and Reaeration Tanks

The waste is then pumped to the inlet box of the activated sludge tank and mixed with reactivated sludge, returned final effluent, and sanitary sewage. The inlet box is a chamber 4 by 4 by 4 ft and carborundum tubes at the bottom disperse air for thorough mixing. The mixture passes over the side to the aeration tank proper and is aerated for 30 hr. The design BOD loading is approximately 85 lb per day/1,000 cu ft of tank volume. The tank is 50 ft in diameter with a water depth of 16 ft and about 1.5 ft of free-

FIGURE 5.—Top of aeration tank.

FIGURE 6.—Aeration tank and final settling tank on left; primary settling tank on right.

FIGURE 7.—Chemical-feed house, oil separator, sludge reaeration tank, aeration tank, and final settling tank.

board. An end-around baffle bisects the tank. A walkway extends the length of the tank directly over the baffle and is discernible in Figure 5. Air is introduced and dispersed by impingement aerators on each side of the baffle. The air capacity of the system is rated at 800 cfm. Normal operation utilizes about 740 cfm.

The reaeration tank, which is similarly constructed, receives the settled sludge from the final settling basin. Air, at the rate of 100 cfm, is introduced through a sparger ring near the bottom and sheared by a propeller mixer located directly above the sparger ring. The propeller action forces the liquid downward past the air outlet. The reaeration tank is 8 ft in diameter with a 16-ft water depth and is designed for 5-hr sludge retention. Figure 6 shows the relative positions of the activated sludge aeration tank and primary settling tank. Figure 7 shows the activated sludge aeration tank, sludge reaeration tank, oil skimmer, chemical and pump house, and final settling tank.

Blowers

Two positive rotary blowers, each having a capacity of 840 cfm, were installed to provide air for the activated sludge tank, sludge reaeration tank, and the air-mixing basin. Only one blower is used at a time.

Final Settling Basin

The overflow from the activated sludge tank enters the distribution chamber of the final settling basin and passes through distribution orifices into the tank proper. The retention time is 2.0 hr. The settled sludge is moved to two sumps at the inlet end and from there it is pumped to the sludge reaeration tank. The effluent passes over multiple weirs at the downstream end of the tank. About 45 gpm is returned to the inlet box of the activated sludge tank. Two 50-gpm sludge pumps are available for sludge handling.

Start-up

Seeding

The initial start-up of an industrial waste treatment plant presents many problems not encountered in a municipal installation because the influent is usually sterile and the organisms necessary for biological treatment must be obtained from another source. Of course, there is some sanitary sewage from the plant personnel, but usually in amounts too small to be used for seed in a waste plant having a capacity that compares to the population equivalent of a medium-size city. For the Franklin, Va., waste treatment plant there appeared to be four possible sources of seed: commercial dehydrated sludge, skimmed milk and animal manure, septic tank sludge, and digester sludge.

After considering the quantities and cost of each seed, it was decided to use digester sludge. Arrangements were made with the Franklin municipal treatment plant, and a septic tank cleaning company was engaged to haul a minimum of 10,000 gal of sludge and whatever additional quantity might be required. In preparation, the tanks and basins had been filled with water, and the aeration equipment was put in operation the evening before the first load of sludge was delivered. The sludge was dumped into the sanitary pump sump, diluted for easier pumping, and pumped directly to the aeration tank. Two or three loads of 1,000 gal each were brought in each day and at the end of the week, with 16,000 gal of sludge in the aeration tank, the industrial waste was introduced at a 10-gpm rate. The excess waste was diverted to the lagoon. At this time, no chemicals were used for de-emulsification. However, both diammonium phosphate and aqueous ammonia had been added directly to the aeration tank.

Increase in BOD

Although the distillation wastes were similar to the pilot-plant samples from the Research Center (Waste D) process facilities were installed for pretreatment of the tall oil. This process resulted in an additional waste not originally contemplated. Consequently, at the time of start-up, the BOD of the raw waste was in the range of 1,800 to 2,400 mg/l rather than 1,200 mg/l. For a number of weeks operation of the process equipment was in a state of flux and the volume and characteristics of the waste varied considerably.

The sludge acclimatized well and the waste feed was increased weekly in about 10-gpm increments until the flow had reached 50 gpm. At this time the BOD reduction was about 90 per cent. The COD, however, was very erratic and changed as much as 400 per cent from day to day, with resulting shocks to the activated sludge tank. In order to guarantee a more uniform load to the system, the plant waste was diverted to the lagoon and then fed directly to the activated sludge tank. This resulted in a relatively uniform COD in the feed. This practice was continued until the design rate of 70 gpm was reached. The initial start-up period spanned about seven weeks.

As a point of interest, the various phases of development of micro-organisms in the mixed liquor followed the general pattern found by McKinney and Gram in their work with protozoa and activated sludge (1).

Performance

With the plant operating at 40 to 50 per cent of capacity, sometimes less, the only visible organisms were bacteria. Free swimming *Ciliata, Paramecia, Amoeba,* and *Holophrya* began to appear as the design-flow rate was approached, becoming more numerous as the BOD efficiency increased. The effluent retained a characteristic amber color, but the cloudy appearance diminished. When the BOD removal reached a level of 80 per cent the free swimming ciliates were joined by an ever increasing number of rotifers, predominantly *Diglena.* This population balance was constant as the efficiency increased to about 95 per cent. However, not a single observation disclosed any sign of the stalked ciliates usually indicative of the high removals and clear effluent now being obtained.

After the waste treatment plant was operating satisfactorily the organisms were not observed for a three-month period. During that period, with removals still in the vicinity of 95 per cent, the population had undergone a complete change. The field was covered completely with bell-shaped, stalked ciliates resembling *Vorticella* with only an occasional rotifer or free-swimming protozoan. Bacteria were present, however, as they were during all stages of the start-up period.

After four months of creditable operation, the average BOD increased from about 2,000 to 3,700 mg/l and the efficiency started to drop. At about the same time, oil began to accumulate in the aeration tank and seemed to form a film on, or was partially absorbed by, the sludge particles.

It was apparent from treatment efficiencies and sludge appearance that the bacteria could not tolerate this oil component. In September, some four months after start-up, de-emulsification was started.

There was now no question about removing the emulsified oils and the necessary chemicals were fed for this purpose. Two unforeseen difficulties arose, however: (a) part of the solids floated as a thick, oily scum; and (b) the scum stuck to the sides of the pipe between the Parshall flume and the primary settling tank and finally plugged it.. The first problem was solved by increasing the amount of

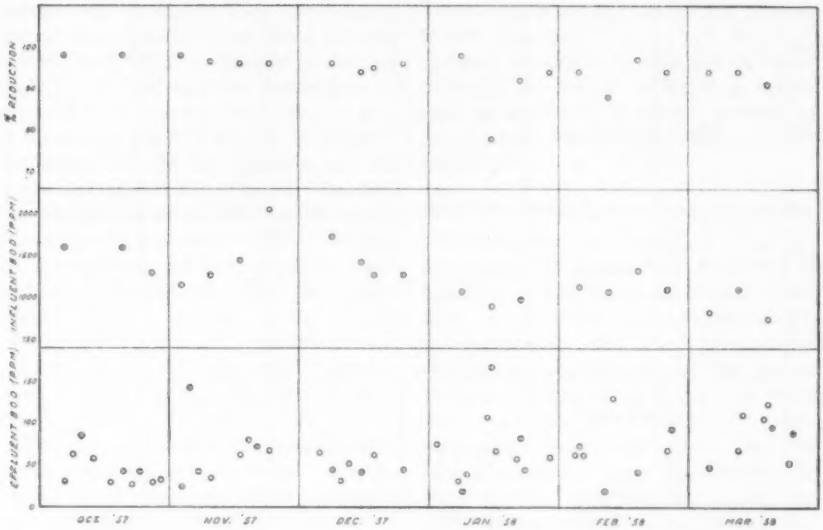

FIGURE 8.—BOD values of the influent and effluent for a recent six-month period.

calcium chloride. The second problem was eliminated by repiping the soda ash to the inlet of the primary settling tanks.

After the techniques had been perfected, good separation of emulsified oils was obtained and the resulting BOD was found to be quite similar to the BOD of the de-emulsified waste samples. With the exception of minor mechanical difficulties, and periodic excessive foaming in the aeration tank, the waste treatment plant has given consistently good results. Figure 8 shows influent and effluent BOD values for a recent six-month period. With the exception of a short period, the BOD reduction has exceeded 90 per cent, usually in the range of 96 to 98 per cent.

Operating Criteria

COD-BOD Ratio

In order to better control waste plant operations, a number of studies were made to correlate COD-BOD ratios, optimum mixed liquor solids, and optimum sludge indexes and ages. The COD and BOD values, as well as the COD-BOD ratio of the de-emulsified wastes, were relatively constant. The COD-BOD ratio of the effluent was found to be a function of the degree of treatment. During the time the plant was being brought up to full load, the ratio was on the order of 3 : 1, but after a few weeks' operation with a high degree of treatment, the ratio increased to 8 or 10 : 1.

Suspended Solids

To determine optimum suspended solids in the mixed liquor, the solids contents were carried at various levels from 1,500 to over 4,000 mg/l. As the solids were increased to 3,000 mg/l, the treatment also improved. Beyond this concentration there was little change in efficiency. However, above 4,000 mg/l, the residual DO decreased and the sludge became bulky and settled poorly. Now, the solids are controlled at the 3,000- to 4,000-mg/l range.

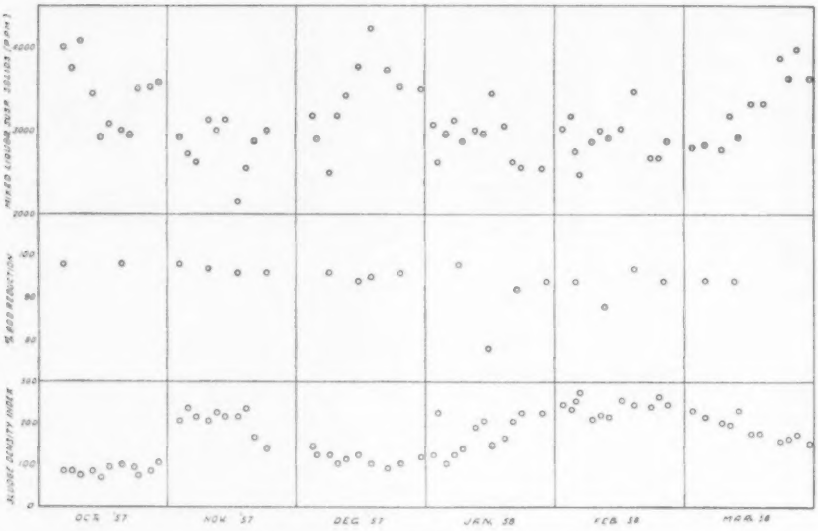

FIGURE 9.—Sludge density indexes, mixed liquor suspended solids concentrations, and BOD removals for a recent six-month period.

Sludge Age

Sludge age (2) was computed from the formula:

$$\text{Sludge Age} = \frac{V \times SS_a}{Q \times SS_i},$$

in which

V = volume of aeration tank, mil gal;
SS_a = suspended solids in mixed liquor, mg/l;
Q = waste flow, mgd; and
SS_i = suspended solids in aeration tank influent, mg/l.

The sludge age, using this formula, is about 3 days.

Sludge Index

The sludge index values shown in Figure 9 do not suggest that the BOD reduction is a function of the sludge index. However, when conditions were such that the efficiency fell off, the sludge index increased. Even after the efficiency returned to "normal" the sludge index continued to increase before it returned to its "normal" range.

Activated Sludge

With BOD loadings of 85 lb per day/1,000 cu ft of aeration tank volume it might be expected that a dispersed type of biological growth would exist. However, the solids content of the mixed liquor, the types of organisms present, and the high degree of treatment do not indicate such is the case.

By knowing the point on the microorganism growth curve at which the plant is operating, it becomes possible to keep operating costs at a minimum. This cost-saving control is brought about by the proper regulation of mixed-liquor temperature and the feed of de-emulsification chemicals. It has been determined that the optimum temperature of the mixed liquor is about 33°C and that temperatures as low as 23°C can be tolerated with little loss of efficiency. It has also been found that satisfactory de-emulsi-

fication can be obtained by cutting out the calcium chloride feed for a certain period each shift. Simply reducing the rate of feed impairs performance, however. It appears that once a floc is formed it has the ability to remove emulsified oils in the portion of the waste not chemically treated. So far, the chemical-feed period has been reduced by 40 per cent without having oil accumulate in the aeration tank and with no adverse effect on treatment. Present studies on the effects of increased loads and reduced chemical and heat additions will continue until a declining growth phase is indicated.

The primary reason for these studies is to reduce chemical costs. Fortunately, a reduction in BOD removals can be tolerated.

Operating Problems

Aspirator

Preliminary studies suggested that the addition of a small amount of air to the raw wastes would improve the floatability of the free oil. Consequently, the wet-well pumps in the lift sump were designed to pump 1.5 cfm of air together with the liquid. Considerable time and effort were spent in adjusting the amount of air passing into the suction line but because the power requirements increased tremendously with only small increases of air, the motor would become overloaded and cut off. It was found that the air addition did not materially affect the flotation of oil and its use was discontinued.

Oil Separator

The oil separator was designed for 90 min retention. A series of flights pushed the oil toward the outlet end of the tank, up an inclined ramp, then into a trough to an adjacent oil sump. This worked well except that after a few weeks the neoprene edges attached to the flights would soften and curl. Teflon edges appear to be the answer to the problem.

For a separator of this size it would probably be better to build a larger tank to maintain a larger volume of oil and skim manually through a slotted pipe.

Lagoon

The lagoon was installed primarily for storage of wastes that could not be handled at the waste treatment plant. Two wood tanks were installed for sedimentation of the precipitated sludge and equalization of the wastes. Experience indicated that these tanks were not always effective in their equalizing role. But when the flow was changed to pass through the lagoon before entering the tanks, the BOD values became more constant and the treatment plant more efficient. The lagoon is not always necessary. In fact, it has been some months since it last was used. But, if stronger-than-normal wastes appear, or if the de-emulsification process should fail, the only way to prevent a shutdown of operations is by lagoon storage.

Of course, the waste plant must continue to operate even when process operations are shutdown and at this time the lagoon serves as a reservoir from which the feed to the waste treatment plant is obtained. Also, it appears that in the lagoon there is a partial breaking of the emulsion. This action could lower the quantity of chemicals required for full de-emulsification and further reduce costs.

Compressors

Positive rotary blowers were installed at Franklin and have given good service. However, at another Hercules plant, turbo-compressors were installed for the same purpose and during a year's operation, have given excellent service. The cost for the turbo-compressors was considerably less and there are two other advantages: the first is quieter operation; and the

second is ease of adjustment of air volumes delivered. The turbo-compressor performance curve is not too unlike the curve for a centrifugal pump, and if the discharge is throttled, the volume delivered and power requirements are reduced accordingly.

Costs

Labor costs have been extremely low because supervision, operation, and laboratory control are all done by people who are required for other duties. For example, the chief plant chemist is primarily responsible for operation, the analyses are performed by a laboratory technician, and the boiler house operators see that the chemicals are replenished and the equipment is maintained. The power requirements cannot be reduced very much after design and installation, although proper maintenance and operation will help.

The biggest expense, and the one that must be constantly studied, is for nutrient and de-emulsification chemicals. There are several ways to introduce nitrogen and phosphorus, but because of the necessity of increasing the pH of the influent, ammonia is superior to the ammonia salts, and a phosphate salt is superior to phosphoric acid. In this case, aqueous ammonia and diammonium phosphate were chosen for nutrient supplementation.

The plant was designed to use the alkalinity of the aqueous ammonia and thus reduce the soda ash requirements. However, it was found that a large portion of the ammonia volatilized before reaching the activated sludge aeration tank. Also, the phosphate was precipitated during the de-emulsification process. Consequently, soda ash is now used exclusively for pH adjustment and the nutrient chemicals are fed directly in the feed line to the activated sludge tank.

After the plant was stabilized, the feed of these chemicals was reduced to the point where there is practically zero residual in the effluent. Operation could be maintained with smaller quantities of nutrient feed but the efficiency would be reduced correspondingly.

Management

Probably one of the most important requirements for successful operation of a waste treatment plant is to have an interested management. To have a plant manager, who, in addition to having a fine sense of civic responsibility, had experience at another plant where extremely toxic wastes had to be treated, is indeed fortunate. The results of this sympathetic attitude to waste treatment are obvious.

Conclusions

The conclusions to be drawn are largely self-evident. First, a full-scale plant can be satisfactorily designed with a limited amount of waste sample and closely controlled laboratory studies. Second, tall oil refining wastes can be successfully treated. Third, through the experimentation and study of interested operating personnel optimum results can be obtained at minimum operating cost.

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Stream Pollution

CHROMIUM-INDUCED CHANGES IN THE BLOOD OF RAINBOW TROUT, *SALMO GAIRDNERII*

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In assaying the toxicity of industrial wastes it has been difficult to set definite limits for toxicity to the biological environment since catastrophic changes can occur in an aquatic biodynamic cycle under a given set of environmental conditions. The fish bioassay, which deals with populations, generally fails because it is primarily concerned with acutely toxic concentrations. This necessitates an interpolation or, more often, extrapolation of the data in order to estimate a biologically safe concentration. Although this standard bioassay procedure proposed by Doudoroff *et al.* (1) has gone far to standardize toxicity studies, the literature still contains a variety of methods which have yielded results of little value except to the original investigator.

Many papers that deal with the toxicity of both trivalent and hexavalent chromium to fish have been reviewed by Doudoroff and Katz (2). Nearly all of the information to date pertains to the concentration of chromium proven to be toxic to the various species of fish studied and is little concerned with the physiological cause of death. Abegg (3)(4), using bluegills, studied changes in tissue fluids and blood specific gravity brought on by exposure to solutions of sodium chromate and sodium dichromate. Sodium chromate had no effect but sodium dichromate caused a slight increase in the fluid content of muscle and a decrease in the blood specific gravity (significant to the five per cent level). He also noted that exposure to dichromate caused some precipitation of the mucous covering of the body.

Fromm and Schiffman (5) reported that exposure of largemouth bass to 94 mg/l of Cr (about ½ the 48-hr median tolerance limit or TL_m) caused initially a slight but not highly significant increase in the oxygen consumption, followed by a gradual decline to 27 per cent below normal after 68 hr of exposure. Coagulated strings of mucus from the anus of all experimental fish were observed prior to death and histological examination revealed severe pathological changes in the gut posterior to the pyloric caeca, which in all probability completely destroyed its digestive function.

No damage to the gill tissue has been reported as being caused by exposure of fish to water containing chromium. It is well established that many metals kill by precipitation of the mucus covering the gills, thereby interfering with the respiratory function of this organ.

Unpublished results obtained in this laboratory have shown that appreciable quantities of chromium are accumulated by largemouth bass placed

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in water containing hexavalent chromium. Tracer experiments using radioactive chromium have shown that small amounts of chromium appear in the musculature and significant amounts appear in the spleen, gall bladder (plus bile), kidney, and liver. Undoubtedly this chromium is distributed to the various tissues by way of the blood stream. The information reported herein deals with the effect of exposure to non-acutely lethal levels of chromium on the physiology of the blood of rainbow trout.

Materials and Methods

The rainbow trout, from 10.0 to 17.0 cm long, used in this study were supplied by the Michigan Department of Conservation and were transported to the laboratory in lots of 100. They were acclimated to laboratory conditions for 10 to 14 days prior to the start of any experimental procedures. The temperature was held at 14 to 15°C and the tap water in which the fish were kept had a hardness of 334 mg/l of $CaCO_3$, total alkalinity of 204 mg/l of $CaCO_3$, and a pH of 8.5 to 8.8. The fish were kept in a constant temperature room under continuous illumination. Each Monday, Wednesday, and Friday they were fed a balanced diet of dry commercial fish food.

Blood samples were collected and analyzed according to methods described in other work (6).

Fish to be splenectomized were anesthetized with MS-222. After anesthetization they were placed in the V-shaped trough and given artificial respiration. A mid-ventral incision, about 1.5 cm long, was made slightly posterior to a midpoint between the pectoral and pelvic girdles. The spleen would usually lie beneath this location. Using pointed forceps, the spleen was withdrawn through the incision and cut off. Negligible bleeding resulted, since the vessels serving the spleen are small, and clotting occurred very rapidly. After removal of the spleen the incision was closed with a single suture, the area dried with a sponge and then covered with collodion. By this time the fish had usually recovered from the anesthetic enough to be returned to an aquarium. When returned to the aquarium the fish showed no abnormal behavior and within 15 min they often fed on trout pellets.

The bioassay of the toxicity of chromium to rainbow trout was run according to the procedure established by Doudoroff *et al.* (1), with modifications as previously described by Fromm and Schiffman (5).

The chromium content of the water was measured colorimetrically using the method of Saltzman (7).

Laboratory Tests

Uptake in Organs

The bioassay of the toxicity of chromium yielded a value of 100 mg/l of Cr for the 24-hr median tolerance limit of rainbow trout. Arbitrarily a working level of 20 mg/l of Cr was chosen for the study of the effect of non-acutely toxic concentrations of chromium on rainbow trout.

Using a combination of both stable and radioactive chromium (Cr^{51}), aquaria were set up so that each milliliter of water contained 18.6 μg of chromium. Three fish with a mean weight of 12.9 g were exposed to this concentration for 24 hr after which they were sacrificed and the spleen, liver, kidney, gall bladder, and a section of the caudal peduncle were removed. The caudal peduncle served as a control since it is predominantly muscle tissue and was not expected to concentrate the chromium.

The mean total uptake of chromium per fish by the liver, spleen, kidney, and gall bladder (with bile) was 72.5 μg during the 24-hr exposure period. Analysis of variance methods showed that only the spleen and gall bladder (with bile) had a significantly higher uptake than the caudal peduncle.

TABLE I.—The Effect of Exposure to 20 mg per liter of Cr on the Blood of Rainbow Trout (*Salmo gairdnerii*).*

Treatment	Hematocrit (ml/100 ml)	Hemoglobin (g/100 ml)	Red Blood Cells Count (million/ cu mm)	Red Blood Cells Length (μ)	Plasma Volume (ml/100 g)	Blood Volume (ml/100 g)
Intact trout:						
Clean tap water	31.8±1.39	6.5±1.27	1.11±0.098	14.69±0.24	2.13±0.14	3.24±0.16
Cr water†	43.8±1.56	6.6±0.25	1.25±0.032	14.93±0.15	1.61±0.12	3.01±0.18
Splenectomized trout:						
Clean tap water	28.5±1.42	5.6±1.13	1.04±0.18	—	2.44±0.12	3.85±0.16
Cr water†	40.6±2.92	7.4±0.51	1.38±0.11	—	1.74±0.10	3.16±0.14

* All values given as mean and standard error.
† Concentration of 20 mg/l.

These results are in accord with previously unpublished information obtained with largemouth bass. The chromium, once inside a fish, must be distributed to the various tissues via the blood. This led to further studies on the effect of chromium on the physiology of the blood of rainbow trout.

Blood Effects Tests

In preliminary work it had already been noted that the per cent of red blood cells (hematocrit) in the circulating blood of trout was significantly increased as the result of exposure to 20 mg/l of Cr. The following experiment was set up to investigate the causes for the rise in the hematocrit and to study the relation of the spleen to this phenomenon.

Forty fish were splenectomized and allowed to recover from the operation for 24 hr. At the end of this time four groups of 20 fish each were treated as follows:

1. Intact fish in clean tap water.
2. Intact fish in water containing 20 mg/l of Cr.
3. Splenectomized fish in clean tap water.
4. Splenectomized fish in water containing 20 mg/l of Cr.

Samples of blood were obtained after 24 hr from 10 fish in each group for determinations of hematocrit, red cell count, and hemoglobin. Red blood cell length determinations were done on intact, but not on splenectomized fish. The remaining 10 fish in each group were used for measurement of the plasma and blood volumes. The data summarized in Table I were compared statistically using analysis of variance, covariance, and t-tests.

The splenectomized and intact fish exposed to chromium had hematocrits significantly higher than those fish, both splenectomized and intact, not exposed to chromium. There was no difference between the chromium-exposed splenectomized fish and the chromium-exposed intact fish.

The blood of splenectomized fish exposed to chromium had a significantly higher hemoglobin content than did blood from splenectomized fish that were not exposed. There was no evidence of differences between other groups.

According to the analysis of variance, the splenectomized fish exposed to chromium had significantly higher blood cell counts than the intact and splenectomized controls. By t-test the intact fish exposed to chromium also had a higher blood count than the intact trout.

By t-test, the intact fish exposed to chromium had significantly larger blood cells than the normal trout in tap water. No measurements were made on splenectomized fish.

By covariance, the splenectomized

fish in tap water had a significantly higher plasma and blood volume than the splenectomized fish exposed to chromium. The experimental evidence did not show a difference in the other groups. When the plasma and blood volumes were expressed as a linear regression of volume on body weight all regression and correlation coefficients proved to be highly significant.

Discussion of Effects

The highly significant increase in hematocrits of normal trout exposed to chromium could be brought about by (a) an increase in cell size, (b) an increase in cell number, and (c) a decrease in plasma volume. These are discussed in the order given.

Normal trout in clean tap water had a red blood cell count of 1.11×10^6 cells per cubic millimeter and a hematocrit of 31.8; therefore, by calculation 100 ml of blood contained 1.11×10^{11} cells and each milliliter of packed red blood cells contained 3.50×10^9 cells. Intact trout exposed to chromium had a mean hematocrit of 43.8. Blood from these fish had, by calculation, 1.25×10^{11} cells per 100 ml and each milliliter of packed red cells contained 2.85×10^9 cells. Assuming that the change in numbers of packed cells was due to change in volume only, the 1.11×10^{11} cells in the normal trout, if changed in volume like those in the chromium-exposed fish, would cause a rise in hematocrit from 31.8 to 38.9. Thus the increase in cell volume could account for 59 per cent of the total rise in hematocrit.

If the cell number increased by 1.40×10^{10} cells per 100 ml of blood and, as calculated above, there are 2.85×10^9 cells per ml of packed cells, then the increase in number could account for 4.9 ml per 100 ml of packed cells or 41 per cent of the increase in hematocrit. Since these percentages were calculated from means, the standard error of these means must be kept in mind when contemplating these results.

Neither a rise in blood volume nor a decrease in plasma volume, which must occur with an increased hematocrit, could be shown to occur by statistical examination of the blood and plasma volume data. However, in all cases there was a tendency for the plasma volume to be decreased in fish exposed to chromium (24.4 per cent for intact fish and 28.7 per cent for splenectomized fish). This plus the tendency for the blood volume to be decreased rather than increased (7.4 per cent in intact and 18.2 per cent in splenectomized fish) would indicate the rise in hematocrit as the result of exposure to chromium was accompanied by an unmeasurable decrease in plasma volume.

Lastly, the data in Table I indicate that the presence of the spleen is not necessary and does not contribute to the increase in hematocrit under chromium stress since significant increases were noted in both intact and splenectomized trout.

Irving, Black, and Safford (8) found that rainbow trout erythrocytes would swell from 1 to 21 per cent, averaging 10 per cent, when subjected to tensions of carbon dioxide above 10 mm Hg. This swelling was reported to be more intense than would be expected if the carbon dioxide tension was the only variable which determined the volume change. In the experiments reported herein, carbon dioxide in the aquaria water was determined graphically (9) using measurements of the alkalinity and pH and was never detected in measurable amounts. It was assumed that carbon dioxide was not allowed to build up to any appreciable extent in the blood of the experimental fish and, therefore, was not a factor causing an increase in size of the red blood cells.

Another cause of an increase in cell volume could be the affinity of the erythrocytes for chromium. If the chromium enters the red cell, the os-

motic concentration might be altered sufficiently to cause water to be drawn into the cell. Since the molecular form of the chromium complex in the blood and in the red blood cell is unknown, calculation of the amount of chromium necessary to change the osmotic pressure in such a way as to cause this increase in volume was not possible.

Hematocrit and Time

During collection of the data that appear in Table I it was noticed that hematocrit determinations made in conjunction with the blood volume measurements on splenectomized fish were consistently higher than other hematocrit measurements of similar fish. The only difference in the two determinations was that the blood for hematocrit, cell counts, and hemoglobin was drawn immediately after the fish were anesthetized; whereas, the blood used in the hematocrit for the blood volume measurement was obtained 10 min after 0.012 ml of T-1824 had been injected into the heart, or approximately 12 min after the fish were anesthetized. Those hematocrits taken immediately are designated as hematocrits at $Time_0$ and those taken 10 to 12 min after anesthetization as hematocrits at $Time_{10}$ in Table II. Two additional groups (sham operated fish and splenectomized fish with no injection of T-1824) were added to check the effect of the dye injection and the operative procedure on the rise in hematocrit.

Significant differences occurred in the $Time_0$ and $Time_{10}$ hematocrits from fish which had been splenectomized; whereas, intact fish showed only slight changes with no statistical evidence of a difference. Under these conditions the spleen, rather than adding erythrocytes to the circulating blood, actually acted as a buffer against sudden hemoconcentration. This function is limited, as evidenced by the tendency of the hematocrit to increase in all groups shown in Table II, even though this increase cannot be verified by statistical methods.

TABLE II.—Mean Value of Hematocrit of Rainbow Trout Taken Immediately and 10 to 12 Min After Anesthetization

Treatment of Trout	Hematocrit		
	$Time_0$	$Time_{10}$	Difference
Intact—clean tap water	31.8	35.0	3.2
Intact—20 mg/l Cr	43.8	46.3	2.5
Splenectomized—clean tap water	28.5	36.6	8.1
Splenectomized—20 mg/l Cr	40.6	44.9	4.3
Splenectomized—clean tap water*	28.5	34.9	6.4
Sham operated-clean tap water	33.6	35.8	2.2

* No T-1824 injected.

Buffering Action

Other evidence of the limited nature of this function is the significant increase in hematocrit in both intact and splenectomized fish exposed to chromium, which would indicate the complete overwhelming of the buffer capacity of the spleen due to prolonged potassium chromate stress.

This buffer function of the spleen against sudden hemoconcentration is somewhat surprising in light of experiments reported by Hall (10) and Hall *et al.* (11). They found that anoxic stress caused a contraction of the spleen in fish and that hemoconcentration occurred under these conditions. Since the present work was primarily aimed at answers to toxicity investigations, and since this limited buffer action of the spleen did not influence the results under chromium stress, further investigation into splenic function was not undertaken. It is of interest to note, however, that Yoffey (12) reported the spleen of all fishes he examined histologically had no muscular tissue and only a few elastic fibers.

Potassium Effects

The results so far have been expressed in terms of milligrams of

chromium ion per liter of water even though the chromium used throughout this work was in the form of potassium chromate. Since potassium chromate does contain substantial amounts of potassium ion, a further study was necessary to consider its effect on the foregoing results.

The fish used in this potassium ion experiment had been kept in concrete tanks and fed trout pellets prior to the time of arrival at the laboratory; whereas, all other fish used were taken from holding ponds. New control and chromium-exposed values of the hematocrit were determined and compared with data from 10 fish which were exposed to a potassium chloride solution having a concentration of 29.8 mg/l of K. This concentration of potassium ion in the potassium chloride solution was equal to its concentration in the potassium chromate solution.

Once again, by t-test, the chromium-exposed fish showed a significant increase in hematocrit; however, there was no evidence of a difference between potassium chloride-exposed fish and the controls and the chromium-exposed fish. The variance (85.55) of the data from potassium chloride-exposed fish was significantly higher than that for the normal controls (13.77) and it was assumed that this was an indication of a state of change. Data from fish exposed to 6.6 mg/l of Cr, the lowest concentration of chromium measured that would increase the hematocrit to a maximum of 43.8, also had a variance (258.75) significantly different from that for normal controls (Table III). Perhaps this increase in variance of samples can be expected at concentrations which are just strong enough to cause an increase in hematocrit in only some of the fish. If this is true, then the potassium ion, in addition to the chromium, is a potential influence on the results obtained with potassium chromate solutions containing 20 mg/l of Cr. This may also partially explain why potassium chromate is considered to be more toxic than sodium chromate. In addition, it questions the practice of thinking in terms of chromium ion concentrations alone when testing such compounds as potassium chromate, especially at the high concentrations involved in acute studies.

Significant Chromium Concentration

Having demonstrated that the hematocrit was significantly increased in fish exposed to potassium chromate containing 20 mg/l of Cr, it was then undertaken to determine the lowest concentration of chromium at which this change took place. The results are shown in Table III.

TABLE III.—Mean Hematocrits of Rainbow Trout Exposed to Different Concentrations of Potassium Chromate

No. of Fish	Chromium (mg/l)	Mean Hematocrit	Standard Error
10	0	31.8	1.39
8	0.5	26.7	2.67
10	1.4	39.3	1.47
9	6.6	43.8	5.08
10	20.0	43.8	1.56

The data show that the hematocrit begins to be affected at concentrations of the order of 2 to 4 mg/l of Cr. This information should be of great interest to the stream pollution biologist since the 24-hr TL_m was found to be 100 mg/l of Cr, yet at these very low concentrations changes in the physiology of the blood do occur.

Since the determination of the hematocrit is a very simple procedure requiring a minimum of equipment, it would be well worth the investigation to determine whether this rise in hematocrit could be used as an index of chronic toxicity in much the same way as the TL_m is used as an index of acute toxicity. It would first have to be established whether an increased hematocrit is a general response to a non-specific stress or a specific response to potassium chromate.

Summary

The 24-hr median tolerance limit of trout to K_2CrO_4 in a concentration expressed in mg/l of Cr is 100. The hematocrits of both splenectomized and intact fish exposed to 20 mg/l of Cr were significantly higher than control fish in clean tap water. Exposure of fish to as low as 2 to 4 mg/l of Cr was found to raise the hematocrit to its maximum value. This rise in hematocrit can be accounted for by an increase in cell number, cell volume, and a probable, but unproven, decrease in plasma volume. The presence of the spleen was found to have no influence on the rise in hematocrit under chromium stress; in fact, the data indicate the spleen may act weakly as a buffer against sudden hemoconcentration. The potential influence of the potassium ion in the K_2CrO_4 on the experimental results is discussed.

Acknowledgments

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INDUSTRIAL UTILIZATION OF MUNICIPAL WASTEWATER *

By C. H. Connell and E. J. M. Berg

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Increased water demands in areas of limited or declining supplies are causing many industries to look at treated sewage as a possible solution to their water problems. In the United States industrial use of municipal wastewater constitutes approximately one per cent of the total available. The potential use possibly is as high as 25 per cent. Ordinarily, an industry uses the lowest-cost water supply which will satisfy its requirements. But fewer than 25 industrial plants have discovered that a sewage treatment plant effluent is a supply of choice. In a few instances such choice was a last resort. In most cases the choice was made after a careful evaluation of all other possible sources on the bases of dependable quantity, uniformity and acceptability of quality, availability and accessibility, treatability, total costs, and over-all community water needs.

Practice

The reports of studies on wastewater reclamation by Merz *et al.* (1)(2)(3) give references and some detail on probably all the major instances of direct utilization of municipal wastewater in the U. S. Extensive information is also included on agricultural and recreational use of municipal wastewater and on reuse of industrial wastewater. These studies plus studies by Gotaas *et al.* (4)(5) and Bush *et al.* (6) constitute basic reference material for anyone interested in reclamation and reuse of wastewater.

In the preparation of this paper the authors have drawn heavily on information given in publications referred to above. Supplementary information has been procured by visits to six of the industrial plants now practicing wastewater utilization and visits to numerous sewage treatment plants that are potential sources of industrial water. Also, questionnaires concerning industrial use of sewage treatment plant effluents were sent to 26 state pollution control agencies, 20 municipalities, 6 industrial plants, and 2 engineering firms. The gratifying, 80-per cent response to the questionnaires revealed only one unreported case of utilization and two contemplated cases. Representatives of most of the state agencies reported no need for industrial use of treatment plant effluents. The enthusiastic responses by representatives of municipalities and industries indicates a much greater potential, however.

Usage

Users

Industrial use of sewage treatment plant effluents is summarized in Table I. The 75 to 118 mgd used for processing and cooling at the Bethlehem Steel Company's Sparrows Point, Md., works constitutes approximately 90 per cent of the total quantity used.

Approximately 6 mgd is used for boiler- and cooling-water purposes at

* Presented at the 13th Industrial Waste Conf., Purdue University; Lafayette, Ind.; May 5–7, 1958.

TABLE I.—Industrial Users of Sewage Treatment Plant Effluents

User	Source of Effluent	Use	Quantity (mgd)
Bethlehem Steel Co., Sparrows Point, Md.	Baltimore Back River treat. plant	Processing and cooling	75 to 118
Kaiser Steel Co., Fontana, Calif.	Plant sanitary treat. plant	Processing	0.5*
Columbia-Geneva Steel Co., Provo, Utah	Plant sanitary treat. plant	Processing	0.3*
Los Alamos Scientific Laboratory, Los Alamos, N. Mex.	Los Alamos treat. plant	Cooling	0.5
Grand Canyon National Park	Park treat. plant	Cooling	0.2
Southern Nevada Power Co., Las Vegas, Nev.	Las Vegas County treat. plant	Cooling	1.7
California Electric Power Co., San Bernardino, Calif.	San Bernardino treat. plant	Cooling	?†
Cosden Petroleum Corp., Big Spring, Tex.	Big Spring treat. plant	Boiler water	0.7
Texas Company, Amarillo, Tex.	Amarillo reclamation plant	Cooling and boiler water	1.5
El Paso Natural Gas Products Co., Odessa, Tex.	Odessa treat. plant	Cooling and boiler water	2.5
Champlin Refining Co., Enid, Okla.	Enid treat. plant	Cooling and boiler water	1.0
Kennecott Copper Corp., Santa Rita, N. Mex.	Santa Rita treat. plant	Copper recovery	0.5*
Kennecott Copper Corp., Hurley, N. Mex.	Hurley treat. plants of 3 towns	Copper recovery	0.3*
Kennecott Copper Corp., Hayde, Ariz.	Hayde treat. plant	Copper recovery	?*
Bagdad Copper Co., Bagdad, Ariz.	Bagdad treat. plant	Copper recovery	?*
Inspiration Consolidated Copper Co., Inspiration, Ariz.	Inspiration treat. plant	Copper recovery	?*
Miami Copper Co., Miami, Ariz.	Miami treat. plant	Copper recovery	?*
Phelps Dodge Corp., Morenci, Ariz.	Morenci, treat. plant	Copper recovery	?*
St. Anthony Mining and Development Co., Tiger, Ariz.	Tiger treat. plant	Copper recovery	?*

* As supplementary water in water reuse systems.

† Water taken from canal in which treated sewage comprises about ¼ the total flow.

four refineries, and a butadiene and styrene plant. The most recent case of utilization is at the Odessa, Tex. plants of the El Paso Natural Gas Products Co. Here, utilization started in August 1957.

At Los Alamos, N. Mex., treated sanitary wastewater has been successfully used for power-plant cooling since 1951. Similar use of the Las Vegas County, Nev., treatment plant effluent started in February 1957. Originally, 0.9 mgd was used. Currently, 1.7 mgd is being used and an ultimate use of 5 mgd is anticipated.

Reasons for Use

At the Kaiser and Columbia-Geneva steel plants and at a number of copper refineries, sewage treatment plant effluents serve as small but valuable supplementary supplies. At the other plants cited in Table I, with the possible exception of the Texas Company's Amarillo plant, sewage treatment plant effluents were the cheapest, adequate water supply.

The Odessa, Tex., treatment plant effluent was the only adequate source for the plants of the El Paso Natural Gas Products Co. Treated sewage was

also the only adequate water source for the Cosden Petroleum Corp. refinery at Big Spring, Tex. This refinery started using treated sewage in 1943 for cooling and boiler water make-up. However, the cooling water usage at Cosden was discontinued two years ago when the phosphate content of the sewage effluent had risen so high that it became more satisfactory and economical to use water from the new city supply.

The decisions to use treated sewage for cooling water at the Los Alamos, N. Mex., and the Las Vegas, Nev., generating stations were based on water conservation needs and water costs. At Los Alamos, the capital saving was estimated at $150,000 and the annual saving is $20,000.

The report by Wolman (7) delineates the considerations given to all possible sources of water prior to the decision of the Bethlehem Steel Co. to use Baltimore's treatment plant effluent. By far, this effluent proved to be the lowest-cost, best-quality water available in sufficient quantity. Recent observations by Merz (2) on costs of the effluent as compared with costs of water available from the Baltimore city supply show why Bethlehem Steel has extended effluent use from the original figure of 50 mgd to more than 100 mgd. Bethlehem Steel pays approximately $10/mil gal for the effluent. City water would cost more than $100/mil gal. The $10/mil gal Baltimore receives for the effluent defrays all but 30 per cent of the City's cost of sewage treatment, exclusive of capital costs.

At Amarillo, the estimated cost to the Texas Company of 1.5 mgd of treated sewage was at the rate of $133/mil gal (8). This rate was to pay for the additional plant construction necessary to provide reclaimed water to meet Company criteria, a 10-mi transmission line, and pumping facilities. Out of the charge of $133/mil gal, $37.50 was to be applied to the cost of sewage treatment plant operation. At that time, Amarillo had enough fresh water to supply the Texas Company at approximately the same price it asked for treated sewage. In addition, the city water would have cost less for final processing and use. Nevertheless, the conservation of fresh water for future needs dictated the decision to reclaim the municipal wastewater for industrial use.

In 1942, the only water available for an essential plant expansion by the Champlin Oil and Refining Co. was the effluent from the overloaded Enid, Okla., sewage treatment plant. This apparently was the first use of treated sewage as cooling water. Actually, a mixture of effluent and raw sewage was used until Enid completed a new sewage treatment plant in 1954. The costs and difficulties prior to 1954 admittedly were high but were deemed entirely justifiable.

Effluent Quality

The additional treatment that must be given to treated sewage to make it suitable for certain industrial uses has been demonstrated to be only slightly different than the treatment that would be required if drinking water were used for the same purpose. Heavier chlorination for disinfection and stabilization has been essential. Impounding for storage has given additional stabilization. The high phosphate and silica content has necessitated a higher degree of softening treatment in some instances. The presence of synthetic detergents has inhibitory effects on cold coagulation and softening processes, and has necessitated greater use of anti-foam agents in boilers. The presence of ammonia, phosphates, and organic matter has given concern about possible increased biological growths in cooling systems, but no serious adverse experience has been reported.

At Baltimore, the Bethlehem Steel Co. provided facilities to remove sus-

TABLE II.—Sewage Treatment Plant Effluent Quality

Constituent	Location of Plant				
	Amarillo, Tex.	Odessa, Tex.	Los Alamos, N. Mex.	Enid, Okla.	Las Vegas Co., Nev.
Total solids (mg/l)	—	1,012 to 1,564	—	700 to 900	856 to 1,026
Suspended solids (mg/l)	1 to 22	12 to 44	25	50 to 75	—
Chloride as Cl (mg/l)	100 to 115	325	—	225 to 300	94 to 154
Sulfate as SO_4 (mg/l)	65	350	—	75	329 to 391
Alk. as $CaCO_3$ (mg/l)	210 to 300	270 to 480	150	400 to 500	—
Tot. hard. as $CaCO_3$ (mg/l)	220 to 270	400	40	150 to 250	400 to 476
Silica as SiO_2 (mg/l)	35 to 75	10 to 40	60	30	18 to 33
Phosphate as PO_4 (mg/l)	10 to 35	75 to 110	15	40	6 to 18
Ammonia nitrogen (mg/l)	0 to 32	10 to 12	3	—	—
Nitrate nitrogen (mg/l)	0 to 30	—	15	—	—
BOD (mg/l)	2 to 66	5 to 29	20	70 to 90	10 to 30
pH	7 to 7.9	7.5 to 8	7	8.4	—

pended solids by coagulation and sedimentation, but such treatment seldom has been necessary (2)(7). Present treatment includes only chlorination and plain sedimentation. The required chlorine dosage has been as low as 2.2 mg/l.

Quality characteristics of the Amarillo, Los Alamos, Odessa, Enid, and Las Vegas County treatment plant effluents are listed in Table II. The principal water treatment processes used in conditioning these various effluents for boiler- and cooling-water make-up are outlined in Tables III and IV.

TABLE III.—Treatment Required Prior to Boiler-water Use

Treatment	Texas Co. Refinery, Amarillo, Tex.	Cosden Petrol. Corp. Refinery, Big Spring, Tex.	El Paso Natural Gas Prod. Co. Plants, Odessa, Tex.
Chlorination	Yes	Yes	Yes
Impounding for storage and stabilization	Yes	Yes	Yes
Hot lime or hot lime and soda ash	Yes	Yes	Yes
Hot sodium zeolite	Yes	No	Yes
Hot hydrogen zeolite	No	No	Yes
Anti-foam agent added	—	Yes	—

The treatment processes at Los Alamos have been the least involved and perhaps the most successful. Here, the effluent is used for five cycles in the cooling water system. At the Las Vegas Co. installation only two to three cycles can be carried because of the hardness and phosphate build-up. Softening of this water is being considered.

At Los Alamos, the excellent control of corrosion and scaling is attributed to the uniformly high quality of water supplied from the well-operated sewage treatment plants and to the close control of chemical dosages to the cycle water. No significant corrosion of the 90-10 Cu-Ni condenser tubes has resulted in five years of operation (Figure 1). Test strips of admiralty metal and 90-10 Cu-Ni have shown penetrations of from 0.0004 to 0.0008 in./yr. Algae control in the cooling towers also has been excellent. No chlorine residual is maintained in the water but every 8 hr a single, large slug of chlorine is applied. Algae control is attributed also to a practice of shutting off each cooling tower for a period of 2 hr each week. During this 2-hr period the cooling tower cell is

TABLE IV.—Treatment Required Prior to Cooling-water Use

Treatment	Texas Co. Refinery, Amarillo, Tex.	El Paso Natural Gas Prod. Co. Plants, Odessa, Tex.	Los Alamos Scientific Lab. Power Plant, Los Alamos, N. Mex.	Champlain Ref. Co. Refinery, Enid, Okla.	Southern Nev. Power Co. Power Plant, Las Vegas, Nev.
Chlorination	Yes	Yes	Yes	No	Yes
Impounding for storage and stabilization	Yes	Yes	—	No	Yes
Cold lime softening or lime and soda ash	Lime & soda	Lime	—	Lime	(Softening contemplated)
Alum	—	Yes	—	Yes	—
Filtration	Yes	Yes	—	No	—
Sodium zeolite	No	Yes	No	No	No
Hydrogen zeolite	No	Yes	No	No	No
Scale and/or corrosion control chemicals	—	—	Yes	Yes	Yes
Chlorination for slime control	Yes	—	Yes	Bromine	Yes
Other slime control chemicals	—	—	—	Yes	—

open to the beneficial effects of the New Mexico sunshine (Figure 2).

In the design and construction of the water reclamation and sewage treatment plant at Amarillo, consideration was given to facilities for producing an effluent of low ammonia content. To this end, chlorinators were provided for adding sufficient chlorine to remove all of the ammonia (8), but their use for such treatment has not been necessary. No difficulties have been attributed to ammonia in the water. As a matter of fact, ammonia in the boiler water has been of some assistance in combating condensate-line corrosion.

Residual detergents in the water have produced foaming in the cooling towers. The maintenance of chlorine residuals of from 1 to 5 mg/l in the cycle water has aided foam control. Slight over-treatment of the water by the cold lime-soda process has been required to reduce the hardness and phosphate content to a level satisfactory for use as cooling water. Hot lime-soda and hot zeolite treatment is required for the boiler-water make-up.

FIGURE 1.—Cu-Ni condenser tube after five years of use, Los Alamos, N. Mex.

At the Cosden Refinery, the Big Spring, Tex., sewage treatment plant effluent is used for make-up for boilers operating at 175 psi. Hot lime-soda softening, hot phosphate treatment, and filtration through an anthracite filter produce a high quality water. However, it is necessary to use an antifoam agent at a fairly high rate.

The phosphate and detergent content of the Odessa, Tex., sewage effluent and the high hardness and solids of the city water made it necessary for the El Paso Natural Gas Products Co. to develop very elaborate systems of water treatment. For cooling water and make-up for 175-psi boilers the following system of treatment is used: (a) cold excess-lime and alum treatment in a 65-ft diameter softener-clarifier (Figure 3); (b) filtration through horizontal pressure filters

FIGURE 2.—Top of cooling cell, Los Alamos, N. Mex.

(Figure 4); and (c) split sodium and hydrogen zeolite treatment to give desired additional softening, alkalinity and solids reduction, and control of pH (Figure 4).

For feedwater for 250-psi boilers a hot system is used which includes excess lime-soda, sodium aluminate, hot filtration, and hot sodium and hydrogen zeolite treatment (Figure 5). In the cold process, the removal of calcium, magnesium, and alkalinity is something less than theory calls for, but phosphate is removed readily. In the hot process, reactions are rapid and complete except with silica, which is difficult to reduce to less than 5 mg/l. Excellent exchange rates are obtained in the sodium and hydrogen zeolite units.

At the Champlin Refinery, Enid, Okla., cold lime is used to render the treated sewage satisfactory for use as cooling water. The primary object of the treatment is to lower the phosphate content. This is reduced from 40 to approximately 5 mg/l. Also, total hardness is reduced from 250 to approximately 120 mg/l. Break-point chlorination of the cooling water was tried with variable success and was discontinued as non-justifiable. Bromine has been used more successfully.

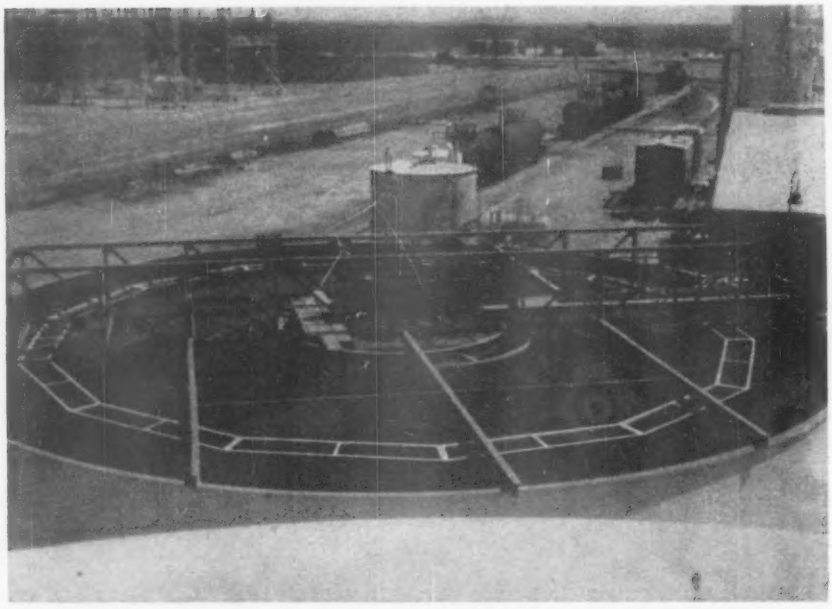

FIGURE 3.—Cold-lime softener, El Paso Natural Gas Products Co. plant, Odessa, Tex.

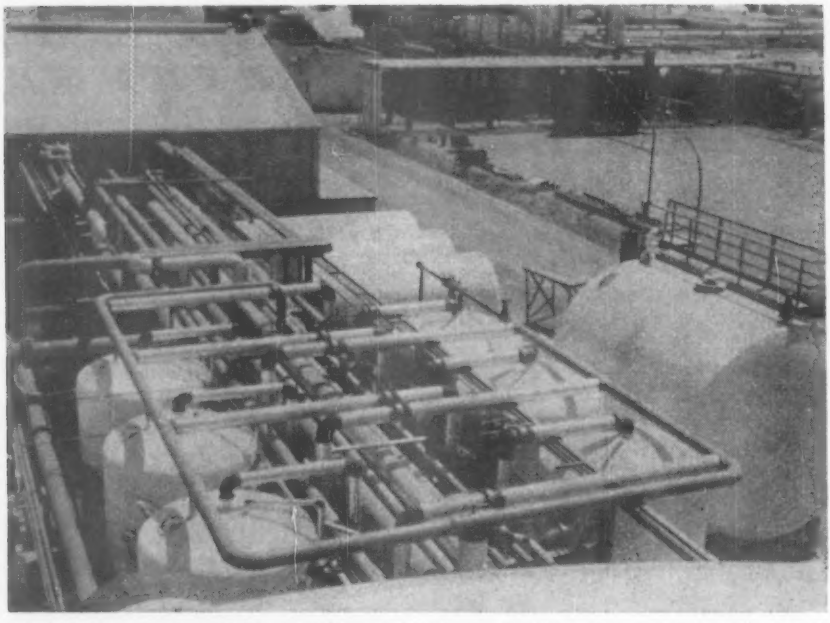

FIGURE 4.—Horizontal filters, sodium and hydrogen zeolite units, and hydrochloric acid storage, El Paso Natural Gas Products Co. plant, Odessa, Tex.

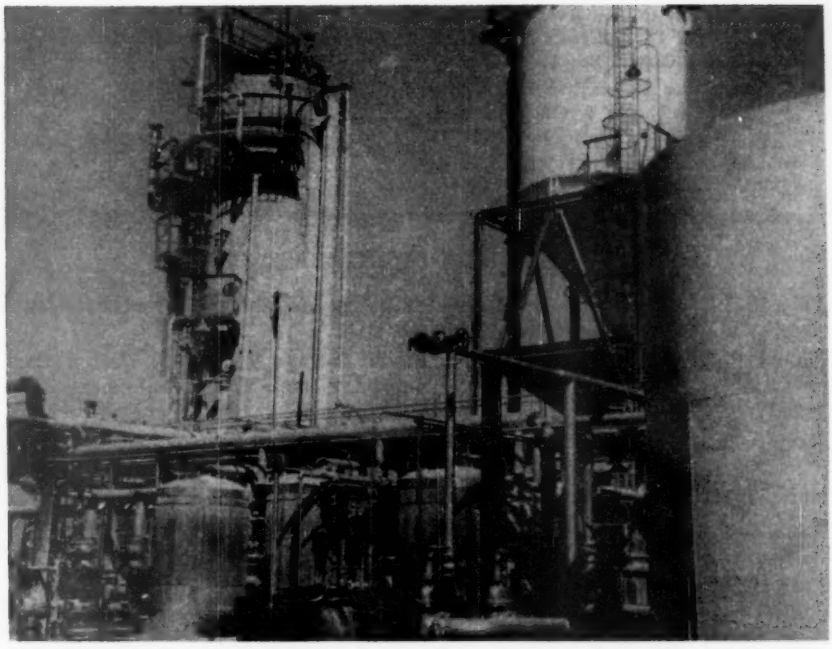

FIGURE 5.—Bulk lime storage, hot-lime softener, and hot-sodium and hydrogen zeolite units, El Paso Natural Gas Products Co. plant, Odessa, Tex.

Health Factors

No adverse health effects have been observed in the industrial use of treated sewage. Heavy chlorination is applied regularly for stabilization and disinfection effects. Surviving pathogens are reduced by subsequent storage and hot lime treatment. In all instances precautions are taken to prevent the interconnection of the industrial water supply with the drinking water supply.

Conclusions

Experience to date indicates that municipal wastewater can and should be given more consideration as a possible source of industrial water supply. Such consideration will lead to increased industrial use of municipal wastewater, especially in areas where competition for water is increasing.

Acknowledgment

Appreciation is extended to the representatives of industrial plants, municipalities, state and Federal agencies, and consulting engineering firms for information and illustrative material supplied for use in this paper.

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MEETINGS OF INTEREST

Feb. 15–19	**American Institute of Mining, Metallurgical, and Petroleum Engineers,** San Francisco, Calif.
Mar. 3	**Third Annual Great Plains Sewage Treatment Design Conference,** Castle Hotel, Omaha, Nebr. V. J. Lechtenberg, 2549 Farnum Street, Omaha, Nebr.
Mar. 16–20	**National Association of Corrosion Engineers,** Sherman Hotel, Chicago, Ill.
Mar. 17–18	**Air and Water Pollution Abatement Conference,** Netherlands Hilton Hotel, Cincinnati, Ohio. Manufacturing Chemists Association, Inc., 1625 Eye St., N. W., Washington, D. C.
Mar. 18–20	**Twenty-second Annual Short Course for Superintendents and Operators of Water and Sewerage Systems,** Louisiana State University, Baton Rouge, La. Fred H. Fenn, Dean, College of Engineering, same address.
Apr. 2–3	**Eighth Southern Municipal and Industrial Waste Conference,** University of North Carolina, Chapel Hill, N. C. Dr. Daniel A. Okun, Dept. of Sanitary Engineering, School of Public Health, same address.
Apr. 2–3	**Ninth Pacific Northwest Industrial Waste Conference,** University of Washington, Seattle, Wash. Professor Robert O. Sylvester, Dept. of Civil Engineering, same address.
Apr. 5–10	**American Chemical Society,** 135th National Meeting, Boston, Mass. R. M. Warren, American Chemical Society, 1155 16th St., N. W., Washington 6, D. C.
Apr. 5–10	**Fifth Nuclear Engineering and Science Conference,** Public Auditorium, Cleveland, Ohio. T. A. Marshall, Jr. (Congress Manager) or L. K. Wheelock (Assistant Manager), c/o Engineers Joint Council, 29 West 39th St., New York 18, N. Y.
Apr. 6–8	**Sixth Biennial Inland Empire Sewage Works Short School,** State College of Washington, Pullman, Wash. Professor G. H. Dunstan, same address.
Apr. 20–24	**Second Seminar on Biological Problems in Water Pollution,** Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio. Clarence M. Tarzwell, same address.
Apr. 24	**Seventh Annual Pennsylvania Clean Streams Conference,** Abraham Lincoln Hotel, Reading, Pa. R. V. Wall, Pennsylvania State Chamber of Commerce, State Chamber Building, Harrisburg, Pa.

THE OPERATOR'S CORNER

A REVIEW OF SLUDGE DIGESTION*

By George T. Lohmeyer

Superintendent, University of Florida Sewage Treatment Plant, Gainesville, Fla.

With few exceptions, the anaerobic sludge digestion process is employed today in almost every sewage treatment plant, regardless of the plant size or complexity. And also, with few exceptions, the average sewage treatment plant operator today does not fully respect and appreciate the biological miracle occurring in the digester until it becomes sick or approaches the acid stage. That digesters have occasionally become sick is not amazing. What is amazing is that even more digesters have not become sick in view of the "pump it to the digester" theme followed in so many plants.

It is perhaps unfortunate that a digester cannot possess the natural beauty of a trickling filter's surface expanse of green algae, or, for that matter, the movement of an activated sludge aeration tank. The action in a digester, being largely hidden, is too often forgotten. Even to a plant visitor the operator of a trickling filter or an activated sludge plant can easily display the remarkable solids removal obtained by the process. However, when it comes to the digester, discretion dictates that the raw material be only mentioned, not viewed.

Operators sometimes fail to appreciate the economy of their digester operation. In the activated sludge process vast quantities of air must be supplied to maintain aerobic conditions and for mixing purposes. In trickling filters a considerable head loss is inherent to the process. On the other hand, in an open digester, the essential features are a concrete tank with relatively minor mixing facilities. For this reason, on a pound-for-pound basis of treating sewage solids, a digester can do the job considerably cheaper.

Theory

What happens in a digester biologically, has been occurring for ages on the bottoms of lakes and ponds. There, in an environment in which oxygen is absent, organic sediment is used as a food source by naturally forming anaerobic organisms. In the process "marsh gas" or methane is formed and rises to the surface of the water leaving on the bottom a mineralized residue of organic matter.

There is considerable material in the literature on man's attempts to duplicate this plan of nature in the anaerobic digester. Nevertheless a great deal more must be learned before the biological reaction which converts highly complex organic matter into such simple gases as methane and carbon dioxide is fully explained.

In reference to this process Bloodgood (1) has concluded that a mixed culture of microorganisms probably is

* Presented at the 26th Annual Short School for Water and Sewage Works Operators; University of Florida, Gainesville, Fla.; June 2–7, 1958.

required and that the methane formers are not necessarily those which attack the complex organic solids. Sawyer and others (2) explain that satisfactory digestion "depends upon having two totally different groups of bacteria living harmoniously in the same environment." They divide these organisms into: (a) the saprophytic organisms, and (b) the methane formers. The first group attacks such complex organic compounds as fats, carbohydrates, and proteins, and converts them into more simple organic compounds. Some of the first group are acid formers which produce such compounds as acetic and propionic acids. The second group, the methane formers, are reported to be capable of utilizing the acid and other products of the first group. The saprophytic organisms also increase in numbers more rapidly than the methane formers.

Regarding the characteristics of methane formation in the sludge digestion process Buswell (3) has concluded that the "microscopic and subculture studies of this fermentation [methane] reveal such a mixed and variable flora that it appears at present [1954] to be environment rather than flora which determines the results obtained." Barker (4), in 1956, on the same subject stated that "little is known about the biochemical mechanisms of methane formation."

In discussing sludge-digestion thermic reactions Phelps (5) states, "Energy exchange is secondary and incidental and quantitatively small compared to the total work done, which is hydrolysis." This indicates little or no heat is generated by the sludge digestion process in itself, and for the plant operator it can be considered neither endothermic nor exothermic. Rudolfs and others (6) reported in 1929 that in an unseeded sludge digestion process the influent sludge is attacked in three overlapping stages. He listed these stages as being (a) intensive acid production, (b) acid digestion, and (c) intensive digestion of the more resistant materials.

In the first stage it was found that sugars, soluble starches, cellulose, and soluble nitrogenous compounds are attacked by the coliform group and by spore-forming anaerobes. Organic acids, hydrogen sulfide, large volumes of carbon dioxide, nitrogen, and acid carbonates are produced. This stage is characterized by a drop in the pH value from 6.8 to 5.1.

The organic acids produced in the first stage, together with certain nitrogenous compounds, are utilized by organisms (then undetermined) in the second stage. This stage results in a gradual rise in the pH value from 5.1 to 6.6 or 6.8, as the rate of the digestion process increases, and is revealed by increased foaming. The products of the second stage are acid carbonates, ammonia compounds, and gases which consist of carbon dioxide, nitrogen, and small quantities of hydrogen.

In the same report it was determined that in the third and final stage, the more resistant materials are attacked. These compounds consist of proteins, amino acids, fats, and possibly lingocellulose, and are attacked by spore-forming anaerobes and fat-splitting organisms. The final stage produces such compounds as ammonia and other protein degradation products, organic acids, and large volumes of gas consisting of a high percentage of methane and smaller quantities of carbon dioxide and nitrogen. With a gradual rise in the pH value from 6.0 to 7.4, a digested sludge is produced which is suitable for disposal.

An operator who has no concept of the obnoxiousness of an acid or sick digester might profit by placing a large beaker of raw sludge in a remote area of the plant to undergo the successive stages of digestion described by Rudolfs. The proper operation of a digester will maintain the entire tank contents in the chemical, physi-

cal, and biological conditions of the final or alkaline stage.

Objectives of Sludge Digestion

Raw sewage sludge is one of the most obnoxious and hazardous materials encountered in the treatment process. The difficult aspects of raw sludge stem from its water-binding qualities, bulk, oxygen demand, and the disease and odor-causing organisms and substances it contains. The purpose of sludge digestion is to overcome each of these objectionable characteristics. To this end it endeavors to:

1. Alter the water-binding characteristics so that rapid dewatering will result.
2. Reduce the initial bulk for economical solids handling.
3. Destroy pathogenic organisms for health protection.
4. Stabilize a sufficient fraction of the organic solids so that noxious odors will not be produced.
5. Recover the methane gas and digested sludge as usable by-products.

In attaining the objectives of proper sludge digestion, so many variables enter the picture that an attempt to establish a standard operational procedure would be futile. No two sewages, no two sewage treatment plants, and no two plant operation techniques can possibly be identical. In spite of these variables, however, certain basic principles can be established which will apply to the operation of all sludge digesters, regardless of their design.

General Principles

The sludge digestion process is one of life, of countless billions of anaerobic organisms living in one environment. No single group of organisms predominates—in fact, a highly mixed culture of organisms is essential. For life there must be food at the proper time, in the proper quantity, and of the proper composition. The food must be mixed with the digester contents so that the organisms can satisfy their food requirements, and at the same time, the total volume of the tank must be fully used. Furthermore, the organisms must multiply, for without the young of a species progress is impossible.

To induce a beneficial bacterial reproductive rate, the correct environment must be maintained. This requires the proper temperature, the necessary alkaline buffering substances, and the absence of high volatile acids, which retard the work of the temperamental methane-forming organisms. Further, this environment must be uniform. There should be no dead spaces, inert layers of bottom grit and sand, or excessively thick top layers of acid-forming scum. Both scum and grit reduce materially the efficiency of the organisms. To insure the existence of a healthy community of organisms, there must be a timely and regular removal of supernatant. The bottom digested sludge must be withdrawn in the right quantity at proper intervals. An over-withdrawal can result in the acid-forming organisms predominating. In brief, the conditions in a digester, whether they are good or bad, are a result of the treatment and care given the organisms by their custodian, the plant operator.

Raw Sludge

The operation of a digester starts in the primary sedimentation tanks and the improper operation of these units can adversely affect the digestion process. Digester organisms prefer sludge that is as fresh as possible because the effect of acid sludge can be overcome only by holding the sludge for a longer period in the digester. Digester anaerobes also perform best if they are fed small amounts of sludge at frequent intervals. They do not flourish on large quantities fed infrequently. Their food requirements are best served by a relatively continuous feeding schedule.

The lack of septicity and frequent sludge pumping are the two requirements for digester influent solids that must be satisfied by efficient operation of primary clarifiers. Low solids-removal efficiencies in primary settling tanks have been traced to excessively long periods between sludge pumpings, during which gas-laden solids rise to the surface of the tank and pass over the effluent weirs.

Another cause of acid sludge, especially in warm climates, is excessive detention time within the collection system, caused by a generally flat topography. Where such conditions exist, and raw septic sludge, which is normally alkaline, is pumped to a digester, a serious burden is placed on the digestion process. Therefore, a digester loaded with septic sludge will appear to be overloaded before the design loading is reached.

Digesters will also develop symptoms of overload if the raw sludge is too watery when pumped. The excessive water dilutes the alkaline digester liquors, decreases considerably the effective detention period, and increases the sludge-pumping requirements. It must be removed largely as supernatant. Such a practice can result in heavy solids concentrations in the supernatant, which if settled in the sedimentation tanks will be recycled to the digester. These recycled digester solids are frequently the cause of the abnormally high digester solids-loading rates which have been reported.

The disadvantage of pumping raw sludge containing too much water has been recognized in the design of large sewage treatment plants and has been remedied to some extent by the installation of sludge-concentration tanks. These tanks aid in the removal of the excess moisture from the sludge before it is pumped into the digester. The volume reduction achieved by concentrating a given quantity of sludge having a particular total solids concentration is considerable. The relationship is governed approximately by the equation

$$V_1 \times S_1 = V_2 \times S_2 \quad \ldots \quad (1)^*$$

In which

V_1 = Volume of the raw sludge;
S_1 = Total solids content of the raw sludge (per cent);
V_2 = Volume of the digested sludge; and
S_2 = Total solids content of the digested sludge (per cent).

As an example, 4,000 gal of a sludge with an initial solids concentration of 3 per cent will be reduced to 2,000 gal in volume if the solids percentage is increased to 6 per cent. Furthermore, if the raw sludge volume is reduced to this extent, the digestion period is approximately doubled.

In heated sludge digesters the reduction of the raw sludge moisture content assumes an even greater significance since every excess gallon of water added must be raised to the digester operating temperature.

Raw sludge, especially that deposited from sewage containing industrial wastes, may contain substances toxic to the digester anaerobes. Copper, cyanides, phenols, detergents, trivalent chromium, free acids, alkalies, and formaldehyde (8), in certain concentrations, have adversely affected digester operation. Sulfite sulfur, in concentrations as low as 50 mg/l, has been reported to have seriously retarded sludge digestion (9) and double this concentration has been reported to have practically stopped the process. Garland (10) reported creosote in concentrations of 33 mg/l caused a serious decrease in digester gas production.

Digester influent sludge is composed of water and volatile and non-volatile solids. Loading rates for digesters are usually computed only on the volatile solids component, which, for average domestic sewage sludge, is

* See ref. 7.

about 2 to 3 per cent of the total weight. This method fails to consider the large quantities of water which must be pumped with the raw sludge in some plants because of design limitations and the nature of the wastes treated. Further, it fails to include the adverse effect of excess quantities of non-volatile solids, such as, for example, waste sludge from water treatment plants.

Starting Digesters

A normal alkaline digestion process is not always achieved easily in starting digesters. When it is feasible, the long acid period can be reduced considerably by "seeding" the tank with organisms and alkaline liquor from another properly functioning digester. A limitation in seeding a new digester is the volume of seed sludge required to provide worthwhile benefits. Van Kleeck (8) recommended a seeding volume of about 20 per cent of the tank capacity, which in large digesters represents a volume of sludge which may be impracticable to transport.

Digesters have been started without seed material by limiting the solids loading rate and thereby preventing the volatile acids concentration from building up excessively. The optimum volatile acids level usually is not over 2,000 to 3,000 mg/l as acetic acid. This is a realistic procedure in a new sewage treatment plant since a new installation rarely will commence operation at the design load. Backmeyer (11) has asserted that a digester which has developed volatile acids of 4,000 mg/l or higher should be emptied and restarted under controlled conditions. The recirculation of digester contents, at the maximum rate, also helps appreciably in the starting of a digester.

Sludge Mixing

When alkaline conditions are established in a digester and gas production rates are normal, a certain amount of natural mixing of the tank contents results. At one time this natural mixing by the rising gas was considered sufficient and it is still utilized to some extent, especially in the sphere-shaped digesters of German design (12). The proper mixing of raw sludge with the digesting sludge is now considered one of the keys to effective sludge digestion. In referring to this phase of digestion control Phelps (13) stated, "This balanced mixture is essential to carry out the complex series of chain reactions which characterize satisfactory operating conditions." One consideration in respect to proper mixing is that the digesting solids should have a sufficient water content so that sludge circulation will not be impeded.

The mixing or stirring of the solids is usually performed by pumps recirculating supernatant or bottom sludge to several alternate discharge points in the tank above or below the scum blanket. A current procedure in covered tanks is to achieve even greater mixing by recirculating digester gas at the bottom-center of the tank. Regardless of the method of mixing, the purpose is to seed raw solids with digesting solids. Secondary benefits include scum control and the maintenance of uniform temperatures throughout the tank.

In a well-loaded single-stage digester an overly vigorous mixing can create problems in withdrawing a clear supernatant and a consolidated digested sludge. These difficulties can be overcome by using a second digester. A rapid biological reaction is achieved in the first unit by recirculation. Supernatant and sludge are withdrawn only from the secondary tank which remains relatively quiescent.

Digester Temperature

The effect of temperature on biological reactions, aerobic and anaerobic, is accepted as a factor of prime influence on sludge digestion. Because the digestion of sludge is a biological phe-

nomenon, the rate of the reaction is decidedly influenced by temperature.

The temperature at which digestion practically ceases has been reported by Phelps (13) as 50° F or slightly less. Bloodgood (1) was in general agreement and stated, "It has been found by practical experience that digestion does not take place at temperatures around 39° F." Buswell (3) found that digestion shows an increase in rate when the temperature rises slightly above 32° F.

Most observers agree, however, that two separate groups of organisms can be established in the digestion process, depending upon the temperature range. One group is the mesophiles, which perform in a wide latitude of temperatures but are thought to work best in the 80° to 100° F range. The thermophilic temperature range, at around 128° F, is rarely used in operation practice because of the difficulty of maintaining the higher temperatures. Obnoxious odors and heavy solids in the supernatant are secondary problems of thermophilic digestion.

A wide disagreement prevails on selecting the optimum mesophilic temperature range. Babbitt (14) reported satisfactory operation of a digester in Bury, England, which had a temperature range of from 51° to 60° F. At this plant the raw solids were composed of domestic and trade wastes, plus waste activated sludge. Furthermore, the gas production, at this relatively low temperature range, averaged 0.71 cu ft per day per capita. It was Babbitt's belief that 85° F was the best practical operating temperature for a digester. Schlenz (15) advocated a temperature of 90° to 95° F, but stressed that this temperature must be uniform throughout the digestion tank. He also discussed the necessity for maintaining this temperature at a constant level, with a minimum of variation. Keefer (16) reported good digestion has resulted at 80° F or even lower. Bloodgood (1) pointed out that sewage solids have been successfully digested at different temperatures. In a four-year study of an open, unheated sludge digester at the University of Florida (17), satisfactory digestion was achieved in a temperature range of from 69° to 83° F.

Fair and Moore (18) prepared the following table relating the digestion temperature and the time of digestion (in days) at which time 80 per cent of the total volume of gas (at 59° F) is produced:

Temperature (° F)	Digestion Time (days)
59	67.8
68	46.6
77	37.5
86	33.3
95	23.7

Phelps (5) reported the digestion process is completed, for all practical purposes, in a period of 30 days at a temperature of 69° F. The over-all picture for the plant operator is probably best summarized by Fair and Moore (18) who reported there are so many variables in the sludge digestion process that there is no exact time of digestion at a given temperature.

Scum Formation

The floating solids which inevitably form to some extent in all digesters, regardless of conditions, have been described (19) as being the "greatest single digestion problem." Wisely (20) in a 1941 survey of the United States found that scum problems existed in 25 per cent of the sewage treatment plants. Even today it is not unusual for plant operators to discuss at length digester scum control during operators' forums held at short courses.

Scum problems are more or less routine in plants handling industrial wastes which contain large quantities of fibrous or low specific gravity materials, such as grease. Fuhrman (21), however, reported digester scum depths of 8 to 10 ft at the Washington, D. C., sewage treatment plant, a plant which treats only domestic sewage.

According to Buswell (3), digester scum is caused by "the rising of lighter material to the surface, where, due to its own buoyancy, it lifts out of the liquid and becomes compact and dry." Scum can be composed of a mixture of raw and digested solids, grease, sticks, leaves, corks, rags, hair, seeds, paper, and other solid material, much of which rises with the gas and is trapped within the floating scum mass.

Scum formations more than 2 ft in depth are to be avoided for many reasons, but the principal concern of the operator is to avoid the loss of digestion capacity. A scum depth of 6 ft in a digester with an effective depth of 20 ft renders 30 per cent of the digester volume totally ineffective. This condition in a digester loaded at its design capacity can result in a poorly defined zone of inferior quality supernatant. Such a tank may show all of the serious symptoms of an overloaded digester. Excessive scum blankets have caused floating covers to tilt and serious damage has resulted to the digester piping and structure, not to mention increased operation costs. Heavy scum formations contain large quantities of volatile solids and volatile acids and the dispersal of these compounds within a tank can send an already "sick" digester back into the dangerous acid stage from which recovery may be difficult, if not impossible.

The control of digester scum layers is generally accomplished by the same devices used in sludge-mixing—the digester recirculation system. Bottom sludge or supernatant is recirculated to points above and/or within the scum blanket. In this manner, active organisms and warm alkaline liquors from underneath the scum are mixed with the floating solids. While good scum control has been attained by this procedure in numerous instances, it is also true that in some digesters it has not been successful in preventing the build-up of scum. Part of the difficulty has been the inability of the operator to inspect easily the condition of the scum and the efficiency of the scum control devices.

In open digesters some investigators (22) feel that a "moderate" amount of scum is beneficial because of its odor-reducing and insulating effect. This is reasonable if "moderate" refers to a scum depth of not more than 2 ft in cold climates, but it is not necessarily true of open digesters operated in a warm, humid climate.

Grit

With rare exceptions, all domestic sewages contain a certain quantity of grit. It is impossible, even in the most perfectly designed and operated grit removal unit, to remove all of the grit contained in raw sewage. In sewage treatment plants which lack efficiently operated grit chambers, grit will inevitably be deposited on the digester floor or bottom. This is especially true in the conventional flat-bottom digesters.

These deposits reduce the effective digestion capacity in direct ratio to their volume. Mau (12) believed that "because of the accumulation of inert sludge, grit, and scum, it is doubtful that more than one-third to one-half of the total volume in many conventional digesters is effectively utilized." The removal of grit deposits are not, therefore, an uncommon problem for the plant operator. Soreff (23) reported the removal of a digester grit accumulation which equalled about 14 per cent of the total digester volume. Grit is a further problem in that it can be picked up by the recirculation pumps, causing excessive wear. Sand clogged sludge lines require no additional comment.

Supernatant

In a properly functioning conventional digester the supernatant zone separates the scum from the digested sludge. It is composed largely of the water component of the influent sludge and relatively small quantities of sus-

pended, dissolved, and colloidal solids and dissolved gases. Because this liquor is from an anaerobic process, it cannot contain dissolved oxygen. It can, however, possess a considerable oxygen demand. The normal procedure for removal is to return the supernatant to the plant influent line at a slow rate during periods of minimum flow. This procedure is entirely satisfactory if the supernatant has a low solids content. Excessive supernatant withdrawals may deplete the necessary buffering agents within the digester.

A good quality supernatant will contain not more than the following concentrations of solids: 0.5 per cent total solids; 2,000 mg/l suspended solids; and 100 ppm settleable solids (8). The volume of supernatant is approximately equal to the volume of raw sludge pumped minus the volume of digested sludge withdrawn.

Many factors affect the quality of the supernatant; the principal one is the digester detention time. Too short a period can result in a supernatant which exceeds the solids concentrations for a good quality liquor. These solids, if returned to the influent flow, often cause reduced efficiencies and operational problems in supplementary treatment units. The results can be: (a) bulking of solids in primary and secondary settling tanks, (b) the organic overloading of trickling filters and activated sludge aeration tanks, (c) increased chlorine demands, and (d) the recycling of solids from the clarifiers to the digesters. Rankin (24) has reported that one plant pumped 30 per cent more solids to a digester than was indicated by the plant suspended solids removal records. He attributed this to supernatant recycling. At the Toledo, Ohio, sewage treatment plant, operation records (25) have clearly shown a decrease in suspended solids and BOD removal when a poor quality supernatant was returned to the plant flow.

In digesters equipped with multiple-pipe withdrawal systems arranged at 2- or 3-ft intervals, supernatant can be withdrawn from the level which produces the lowest solids concentration. With certain patented supernatant selectors, the plant operator can not always choose the level at which to withdraw the supernatant.

Supernatant withdrawal should be made slowly. An excessive velocity can create turbulence in the withdrawal line, resulting in a poor quality supernatant. In sewage treatment plants which have operator supervision 24 hr per day, the supernatant can be withdrawn during the periods of low nighttime flows.

A maximum quiescent period for the digester contents will produce an improved quality supernatant. The settling period will vary with plant conditions, although a minimum of 24 hr is generally practical. During this time digester recirculation is discontinued. In small digesters, with diameters of about 30 ft the supernatant quality can be adversely affected by the pumping of raw sludge. This is especially true in small single-stage digesters equipped with supernatant withdrawal systems located in the center of the digester. It appears that in such installations the ideal point of supernatant removal is a location most remote from the entrance point of the raw sludge. This point is on the side of the tank opposite the raw sludge feed line.

The pumping of a raw sludge high in water content can develop serious supernatant disposal problems. Every excess gallon of water pumped to a digester must be removed, generally as supernatant. The removal of the additional water reduces the digester buffering ability, which in turn decreases the rate of digestion, and increases the supernatant solids content.

Other supernatant problems may be remedied by reducing the scum thickness if it is more than 2 ft in depth, and by utilizing two digesters in stage

operation. In this system the secondary tank remains in a relatively quiescent condition and the supernatant is removed from it.

Supernatant disposal can be a difficult problem. A good quality supernatant can be added to the plant flow and ignored. Schlenz (15) has recommended the discharge of supernatant directly to trickling filters. This will produce a more uniform sloughing of the filter slimes and prevent filter clogging tendencies. In this procedure the quality of the supernatant appears to be the governing factor. In a process devised by Kraus at Peoria, Ill., the digester supernatant is aerated with the returned activated sludge. Reduced bulking and a less temperamental activated sludge process are attributed to this method. Supernatant can also be disposed of on (a) drying beds and plant lawns, (b) in lagoons, and (c) by chemical treatment followed by sedimentation. Undoubtedly, the best method of supernatant disposal has been proposed by Babbitt (14) who said it is the "one which fits local conditions and experiences."

Digester Gas

The collection and utilization of sludge gas for digester heating and other plant purposes is of particular importance in northern climates and in the larger sewage treatment plants elsewhere in the United States. Rudolfs *et al.* (6) reported a daily gas production range of from 0.60 to 0.75 cu ft per capita and Van Kleeck (8) reported a range of from 0.5 to 1.3 cu ft. About 18 cu ft of gas are produced per pound of volatile solids destroyed (8). Bloodgood (1) stated that the heat value of digestion gas varied from 585 to 646 Btu per cubic feet and Babbitt (14) using another parameter, reported that 1,000 cu ft of sludge gas was equivalent to 5.2 gal of gasoline.

Where the heating of digesters is necessary, the cost of providing and maintaining heating facilities is balanced economically by the reduced sludge capacities required. At the same time the complexity of digester maintenance is increased. Further, sludge gas mixed with air is highly explosive and the dangers of explosion and gas asphyxiation are always present in such facilities. On the other hand, accurate records of gas production rates provide an excellent index of the condition of the digestion process.

Digested Sludge

As sludge digestion proceeds there is deposited on the digester bottom a layer of stabilized solids. If these solids are not removed regularly, part of the solids will be carried away in the supernatant. At the other extreme, if a complete removal of digested solids is made an acid digester will result. This is caused by the loss of seed organisms and alkaline substances. Obviously an acid digester is a much more serious condition than an inferior supernatant; therefore, it is better for an operator to draw too little than too much digested sludge.

Probably the best rule in this respect is to withdraw the digested sludge frequently in small volumes rather than infrequently in large volumes. Keefer (16) recommended the withdrawal of sludge when the upper level of the sludge zone reached within 1 ft of the normal supernatant layer. This determination is difficult, except in digesters equipped with side sampling ports. Depth sampling devices leave much to be desired, consequently the withdrawal of sludge in many small treatment plants is guess work based on experience.

Digested sludge should be withdrawn slowly over a period of several hours. Rapid withdrawal can cause the removal of undigested solids from the upper regions of the sludge zone. The proper rate can be checked by observing the nature of the solids being withdrawn.

A well-digested sludge should be black in color and have a tarry odor, but otherwise it should be completely unobjectionable (13). The development of water streaks in freshly drawn sludge and rapid dewatering are additional indications of a well-digested sludge. Also, there should be no undigested solids present. Heated digesters (15) generally produce a sludge of 40 to 50 per cent volatile matter. Wet sludge from these digesters, as reported by Schlenz (25), will contain an average of 5 to 15 per cent dry solids. The remaining part is water which is contained in the following forms and percentages of the total:

Form of Water	Percentage of Total
Free	53
Capillary	42
Combined	5

Sludge Dewatering

Wet digested sludge can be dewatered on vacuum filters. Where there is reasonably good drying weather the normal procedure for medium-size plants is to dewater the sludge to a solids content of 25 to 30 per cent on open drying beds. For the most economical use of drying beds the sludge should be drawn to a wet depth of 8 to 12 in. Schlenz (25) stated that the drying process is expedited by withdrawing a sludge in which the gas production has not quite stopped because the rising gas bubbles produce vertical openings through which water can escape by draining or evaporating. The drying time depends on the amount of rainfall, wind action, air temperature, and humidity.

Dried pulverized sludge is an excellent soil conditioner because of its organic humus content and moisture-holding properties. Other constituents are nitrogen, phosphoric acid, and potash. The concentrations of these compounds vary widely with local conditions. Excessive rainfall on a drying sludge will reduce its plant nutrient content by the leaching of soluble compounds.

Air-dried sludge should be used cautiously because of the possibility of disease transmission. However, Phelps (13) has stated, "Although digested sludge has been extensively used under a variety of conditions, no cases of intestinal diseases have ever been reported as traceable to such use." He cautioned that "further controlled experiments are necessary to allay all suspicion."

That life can survive the digestion process is shown by the sprouting of tomato seeds in the dried sludge. Keefer (16) stated that in a properly functioning digester, most of the pathogenic organisms die in 10 days, with typhoid organisms surviving only about 7 days. It appears that detention time, already admitted to be one of the primary considerations in the design and operation of digesters, is also an important factor in disease control. In spite of the fact that average detention periods in digesters are 30 days or longer, every precaution should be taken in the use of dried sludge.

Digester Reactions

Laboratory Tests

Various laboratory tests are used in determining the condition, progress, and efficiency of an operating digester. Among these tests are the pH, alkalinity, volatile acids, gas production and analysis, percentage total solids, and percentage of dry solids made up by the volatile and non-volatile compounds. Tests should be performed according to "Standard Methods" (26).

Sampling

The results of laboratory analyses are no better than the sludge sampling technique used. In digester solids analyses, the results of single grab samples are rarely reliable. Solids analyses of raw and digested sludge

should be made on composited samples only, made up from a reasonable number of single samples which have been properly preserved. One investigator (27) believed that samples for raw sludge solids analyses should be composited every minute during the primary sludge pumping period. While such a practice is theoretically sound, it could rarely be considered practical for the majority of plants in which sludge samples are taken manually. Common sense dictates that digester recirculation samples should be taken only after a reasonable recirculation period.

Solids analyses on digested sludge are the most reliable because of the relatively uniform concentration of solids. Supernatant is variable to a certain extent, and the solids concentration of raw sludge varies even more. Extreme care is needed in obtaining accurate volumetric measurements of supernatant and raw and digested sludge. Generally, the order of decreasing accuracy in determining these volumes is: (a) digested sludge, (b) supernatant, and (c) raw sludge. This is identical to the order of solids sampling validity.

pH

The hydrogen ion concentration, or pH of a digester is relied on extensively in judging the general conditions of the anaerobic reaction. In most digesters, a neutral condition, as indicated by an average pH value of from 6.8 to 7.2, is considered normal. To a certain extent it represents a proper balance between the materials entering and leaving the digester. A pH value in this range also indicates the presence of certain buffering substances. Barker (4) reported that the most effective pH range for the methane-forming bacteria is from 6.4 to 7.2, with a decrease in activity above 8.0 and below 6.0. An unusually high pH on a single sample can result from the release of carbon dioxide caused by excessive agitation of the sample before analysis.

Alkalinity

Another aid in the laboratory control of a digester is alkalinity. Calcium, magnesium, and ammonium bicarbonates are examples of buffering substances normally found in a digester. Ammonium bicarbonate is produced in the digestion process and the others are normally contained in the raw sludge. Sawyer and Schmidt (28) reported that in analyzing the high-rate digestion process the pH and alkalinity in a sludge mixture varied directly with the concentration of the total raw solids added and with the digester detention time. Backmeyer (11) warned that the alkalinity test can be misleading during an acid phase of digestion because high alkalinities can parallel high volatile acids. He recommended maintaining a total alkalinity of 2,000 mg/l in a well-established heated digester.

Lime additions have been made to digesters with and without success to control the pH and alkalinity. Schlenz (15) stated that liming has been "detrimental in as many instances as it has been beneficial in others." Buswell (3) asserted that "lime in any form or amount has no place in a digester" and reported that in some instances the addition of lime has stimulated volatile acids production. On the other hand, Copeland (29) said that beneficial results have been obtained in a number of digesters by adding lime. He warned that the addition of lime must be accompanied by an effective mixing of the tank contents. Van Kleeck (30) advocated the liming of digesters for the following conditions:

1. An excessive withdrawal of digested sludge.
2. A shock load of industrial wastes high in volatile solids.
3. An overload of toxic wastes, such as copper.

4. A heavy scum blanket high in raw solids.

Satisfactory sludge digestion has been obtained in digesters in which the pH and alkalinity determinations have reflected appreciable departures from accepted values. Such conditions are not too surprising when the number of variable factors in the process are considered. Even so, pH and alkalinity tests are not to be considered useless. Their value lies not only in the exact results, but in the trend or pattern they reveal.

Volatile Acids

The concentration of volatile acids, the intermediate digestion products, is considered to be one of the best digester-control tools. Schlenz (15) stated that the concentration of volatile acids as mg/l acetic acid, will foretell the approach of digestion difficulties in advance of pH, alkalinity, and gas-production changes. Backmeyer (11) believed the inclusion of the volatile acids test in the starting operation of an unseeded digester was imperative. Investigators differ in their recommendations of an upper limit on the concentration of volatile acids in a digester. Buswell (3) believed this concentration should not exceed 2,000 to 3,000 mg/l whereas Schlenz (15) believed 2,000 mg/l should be the upper limit. Copeland (29) and Backmeyer (11) believed the volatile acids in a satisfactory digestion process must be maintained around 300 mg/l. In fact, Backmeyer (11) stated "digestion contents which have volatile acids over 3,000 mg/l are very odorous and undesirable to handle without special means for odor control."

Gas Production

Van Kleeck (8), in discussing digester control analyses stated "A record of gas production is equal to any and all of the various laboratory tests." Schlenz (15) believed the volatile-acids test rated higher than gas production records in determining the progress of the reaction. In digesters equipped with gas collection and gas metering systems, accurate records should be maintained and the results correlated with the routine control analyses.

Summary

The best over-all results with the least difficulties will be produced when the sewage treatment plant operator in charge will manage the digester according to the following points.

1. Keep the entire sewage collection system free of grease, septic sludge, and grit deposits, so that the raw sewage entering the treatment plant will be in as fresh a condition as possible.
2. Eliminate materials which will cause scum, inert bottom digester deposits, or which will be toxic to the digester anaerobes. This includes such items as large quantities of seeds, sand, and certain toxic industrial wastes.
3. Keep the water content of the raw sludge pumped to the digester at a minimum.
4. Pump raw sludge in small amounts at frequent intervals rather than large amounts infrequently.
5. Mix the digester contents on a regular schedule so that the scum blanket is never more than 2-ft thick, and preferably much less. Once each week the depth of the scum blanket should be measured.
6. Prevent rapid temperature increases or decreases in the tank contents. A rise or fall of 5°F in 24 hr can cause a drop in the rate of sludge digestion.
7. In heated tanks maintain a nearly constant temperature level. The exact temperature should be determined by such local conditions as the gas production, the gas demand, the solids-loading rate, the digester capacity, the digester insulation, and the air temperature.

8. Frequently withdraw supernatant in small amounts from the clearest zone in the digester.

9. Prevent the discharge of a poor quality supernatant (a supernatant with more than 0.5 per cent total solids) to the plant. A supernatant with a high solids content can be discharged to an idle sludge drying bed. A supernatant low in solids is an excellent liquid fertilizer, rich in nitrogen, and can be used on plant lawns.

10. Withdraw digested sludge in small amounts, at frequent intervals. Each withdrawal should be made at a slow rate and visually inspected during the entire withdrawal.

11. Follow precisely the recommendations of the manufacturer on the maintenance of all specialized equipment such as floating covers, gas meters, flame traps, pressure regulators, mixing devices, etc.

12. Learn the details of the digestion facilities—the piping layout, the gas collection system, and the mixing devices. No other person should know this better than the plant operator.

13. Maintain accurate records on the following volumetric measurements:

(a) Gallons of raw sludge pumped daily to the digester.
(b) Gallons of supernatant withdrawn.
(c) Gallons of digested sludge withdrawn.

14. Collect samples of the following types:

(a) A composited sample taken daily from raw sludge pumpings.
(b) A composited sample taken during each digested sludge withdrawal.
(c) A composited sample taken from the digester at the end of each period of intense mixing.

15. Make the following laboratory determinations on the samples collected under Item 14:

(a) Temperature average (° F);
(b) Total solids (%);
(c) Volatile solids, dry weight (%);
(d) pH;
(e) Alkalinity (mg/l).

16. Make all, or part, of the following general calculations involving the sludge digestion process:

(a) Gallons of raw sludge pumped per million gallons of raw sewage flow * (gal/mil gal);
(b) Approximate period of digestion (days), monthly average,

$$\text{Digestion period (days)} = \frac{\text{Digester volume (gal)}}{\text{Raw sludge pumped per day (gal/day)}};$$

(c) Pounds of raw total solids added daily per cubic foot of digester volume (lb total solids/day/cu ft), monthly average;
(d) Pounds of raw volatile solids added daily per cubic foot of digester volume (lb volatile solids/day/cu ft), monthly average;
(e) Pounds of suspended solids added daily per cubic foot of digester volume (lb suspended solids/day/cu ft), monthly average;
(f) Per cent reduction of raw volatile solids, average for six months or longer,

$$\text{Reduction (\%)} = \frac{RV - (DV + SV)}{RV} \times 100 \quad . . (2)$$

In which:

RV = Pounds of raw volatile solids to digester during period.
DV = Pounds of digested volatile solids leaving digester during period.
SV = Pounds of supernatant volatile solids leaving digester during period.

* Should be done each day.

(g) Gas production in cubic feet produced per capita, cubic feet produced per pound of volatile solids added, and cubic feet produced per pound of volatile solids destroyed.

17. Study the digester operation techniques used by other operators in the area. One excellent means of accomplishing this is to join a professional association of water and sewage works operators, established on a statewide basis. Tips on sludge digesters are bound to be exchanged among operators at the meetings of the various groups in such an association.

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EVALUATING PROTECTIVE COATINGS*

By Herman J. Estrada

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A program of testing and evaluating coatings for the City of Los Angeles has been in progress at the Bureau of Standards of the Department of Public Works for more than thirty years. The scope of the program has grown with the increase in use of protective coatings and the great increase in the numbers and types of coating materials. Included in the program is an extensive test series which has been carried on in conjunction with the Harbor Departments of the City of Los Angeles and the City of Long Beach.

The cooperative program consists of exposure tests in various locations and environments which are selected to duplicate as nearly as possible the actual conditions of service. Protective coatings intended for use in sewers are exposed in a sewer chamber where concentrations of hydrogen sulfide gas have exceeded 25 ppm and where 5 per cent concentrations of sulfuric acid have been found in the wall moisture.

Service conditions in sewer structures are so diverse that they cannot be fully duplicated in the laboratory. Therefore, accelerated tests in the laboratory are seldom used because the results of such tests do not correlate well with standard exposure tests or with performance in service.

The selection of protective coatings for municipal structures gives rise to many problems. The answer must often be a compromise between the cost and the quality of the coating. Since contracts are awarded to the lowest bidder, specifications must be carefully written to define the type and quality of coating desired. Loose or carelessly written specifications are likely to result in unsatisfactory work.

Liners vs. Coatings

The materials tested for the protection of sewers fall into two general classes: liners and coatings. Liners are generally plastics or elastomers which are extruded or molded to form dense homogeneous sheets of uniform thickness. This minimizes pinholes and other surface defects common to coating systems. Plant control of the compounding and cure minimizes or eliminates the need for plasticizers, solvents, and other ingredients which may reduce the chemical resistance of the protective cover.

The field methods of joining liner sheets may prove unsatisfactory since the composition of the joint material may be different from that of the liner. This difference in composition may weaken the protective system. The present method of testing protective liners uses an electronic spark-tester which indicates breaks in the protective film but does not indicate a poor bond between sheets. Therefore, constant inspection of field joining operations is advisable to minimize poor bonds between sheets.

When considering protective materials for use in areas of severe corrosion or in moderately corrosive locations where future repairs are not practical, a liner may prove more satisfactory than a coating.

* Presented at the 1958 Annual Meeting, California Sewage and Industrial Wastes Assn.; Stockton, Calif.; Apr. 23–26, 1958.

At present, the City of Los Angeles uses a vinyl chloride plastic liner for protecting concrete and steel in such locations. This plastic liner has been in use for more than ten years and has proved satisfactory. Present indications are that a service life of several decades will be realized.

The liners are excellent protective systems and should be considered in those locations where their high initial cost can be offset by their long service.

Protective Coatings

Testing

Protective coating materials are liquids or pastes which can be applied to surfaces by various methods, such as brushing, spraying, or troweling.

When a new sample of protective coating is submitted for test the manufacturer is requested to identify fully the material and furnish information pertinent to its use. If the manufacturer coats the specimens he must furnish information on the surface preparation of the specimens, type of priming, number of coats, method of application, and the dry film thickness.

The specimens are exposed at the various locations and periodic inspections are made at intervals of three to six months. This is a time-consuming method of evaluation requiring many years before full approval can be given to any one material. Even with this care, approved materials have failed in a few installations due to unforeseen conditions that have developed.

Basis for Selection

When selecting a protective coating system for a sewer structure it should be remembered that no single coating or coating system is the best for every situation. Some of the important factors to be considered in the selection of a coating material are the type and present condition of the surface, working conditions at the job site, and any special environmental factor or condition. If the surface is being recoated, experience with the previous coating materials should be studied and evaluated. When applying a new material over an existing coating their compatability should be tested. If they are not compatible the existing coating must be entirely removed. Porous concrete surfaces may require a seal coat to obtain optimum results. A specification should indicate the methods of surface preparation and application. It should be remembered that there is no substitute for a thoroughly cleaned surface when applying a protective coating. Special precautions should be taken when coatings are being applied in a humid atmosphere. Freshly cleaned surfaces in these areas should never remain uncoated for more than a few hours.

The working conditions are important and such factors as adequacy of ventilation, possible presence of explosive gases, feasibility of blast cleaning, and methods of application should be considered when selecting a protective coating.

Consideration should be given to such environmental factors as the average and maximum temperatures, the average humidity and the presence of condensation, exposure to weathering, the presence and possible concentrations of chemicals and solvents, and possible wear and abrasion in service.

The total cost of the various protective systems should be balanced against their life expectancies. A material with a long service-life may prove the least expensive in annual cost.

In sewer structures the feasibility of repairing or replacing the coating system at a future date must be considered as an important controlling factor since it is nearly impossible to repair or recoat many of these structures after they are placed in service. In such locations a protective system with a long service-life should be used.

The following rules of thumb may be generally applied in the selection of

a coating material: The better the material wets and adheres to a surface the poorer will be its chemical resistance; the more flexible the material the poorer will be its chemical resistance; the thicker and more uniform the film thickness of a coating the better the protection. The paint system which is least demanding in surface preparation and application, and which is still capable of performing well is generally the best choice.

When specifying the type of coating material required, the formulation of the coating compound should also be specified. A protective coating consists of various components any of which may be varied or substituted in the different formulations thus changing some of the characteristics of the finished product. The number of variables in coating formulations makes it impossible to state that any one type of coating material is the best for a given location. One formulation of a coating material may afford excellent protection while a variation in the formulation may result in failure of the coating material in a relatively short time.

The following discussion will cover the newer types of protective coatings, their main characteristics, and general information obtained during the test program.

Alkyd Varnishes

The alkyd resins are usually made by the reaction of drying-oil fatty acids and polyhydric alcohols. As a result, they have many of the properties of the drying oils. As the amount of drying oil is decreased the resins become harder and more resistant, but their wetting ability is decreased. The possible variations in types and amounts of drying oils and polyhydric alcohols result in an almost unlimited number of alkyd resins which can be produced.

Alkyd varnishes have weathering properties superior to other oleoresinous enamels. Their gloss and color retention are excellent and the alkyds are excellent for protecting structural steel. The alkyd varnishes are extensively used as coatings on structures not immersed in water or exposed to strong chemicals.

Alkyd varnishes are often modified with rosin to reduce cost. The modification reduces color retention, water resistance, and durability.

Phenolic Resins

Phenolic varnishes are moderately resistant to inorganic acids and mild alkalis. They have excellent resistance to high humidity and water immersion. A short oil-length formulation should be used for maximum water and chemical resistance. The short oil-length formulations are too brittle for outdoor exposure. Exterior durability requires a phenolic varnish based on a long oil length, which will be unsuitable for total immersion.

The phenolic varnishes are more chemically resistant than drying oils, ester gums, and alkyds. Considerable use is made of phenolic varnishes in locations involving high humidity and water immersion and in mild chemical environments which do not warrant paints such as vinyls or chlorinated rubbers.

Phenolic varnishes have poor wetting power and require thorough surface preparation. The phenolic resin is dark, therefore, it cannot be used in light colors.

Phenolic resins may be modified with materials such as rosins, tall oil, and ester gum to produce inexpensive resins. The modification reduces the durability and chemical resistance.

Vinyl Paints

The vinyl resins used as protective coatings are a series made from copolymerized vinyl chloride and vinyl acetate. The vinyl resins have poor adhesion, therefore, constituents such as maleic acid are added to improve ad-

hesion. The adhesion is also improved by applying over a vinyl butyral wash primer. New primers have become available recently which improve adhesion of vinyls, in some cases even where old coatings remain on the surface. For maximum protection the vinyl paints must be applied to sand-blasted surfaces by skilled painters.

Most vinyl paints have a low solids content and numerous coats are needed to build up a thick film. New high-solid vinyl paints and vinyl mastics have been developed recently and are being included in the Bureau's test program.

The vinyls have good flexibility, abrasion, and weather resistance, and good chemical resistance to mineral acids, alkalies, mineral and vegetable oils, and petroleum solvents. They show poor resistance to some organic acids, ammonium hydroxide, and some strong solvents.

These vinyl coatings should not be confused with the water emulsion vinyl acetate paints which are in common use as house paints.

Chlorinated Rubber

Chlorinated rubber is obtained by treating natural rubber with chlorine. The material is a hard resin; plasticizers and other resins are added to make elastic coating materials.

The great variations which occur in the amounts of chlorinated rubber, amounts and types of plasticizers, and other resins can greatly affect the performance of the coating film.

Chlorinated rubber paints are generally classified into three types.

Type A contains over 50 per cent chlorinated rubber in vehicle solids and includes chlorinated resins and plasticizers. This type has the maximum chemical resistance.

Type B contains the same amount of chlorinated rubber as type A but oil and alkyd resins are used to replace the chlorinated resin. It is used primarily on alkaline surfaces such as concrete and masonry.

Type C contains 20 to 40 per cent chlorinated rubber and 60 to 80 per cent long-oil alkyd or drying oils in the vehicle solids. Type C has maximum adhesion but the least chemical resistance. It is widely used as a primer.

Most chlorinated rubber base coatings have a high resistance to many acids, alkalies, and mineral oils. They have poor resistance to strong acetic acid, animal and vegetable oils, and strong solvents.

Epoxy Resins

The epoxy resins are relatively new materials, but present indications are that they will solve some of the problems encountered in protecting sewer structures. Some of their advantages are excellent adhesion, excellent chemical resistance to most solvents, non-oxidizing acids, and caustics, rapid setting time, with no solvent release and very slight shrinkage. The room-cure resins can be obtained in various viscosities. The viscosities vary from light brushing consistency to a heavy troweling consistency.

Some of the disadvantages encountered are the close control required on the proportions of hardener to resin, pot lives as low as 20 min, poor resistance to oxidizers such as chlorine, and poor outdoor weathering performance when used as a clear coat.

Epoxy ester paints are formed by reacting epoxy resin with the fatty acids of a drying oil to form a conventional air-drying oleoresinous paint. The paints have good adhesion, toughness, and abrasion resistance but the chemical resistance is lowered.

Polyurethanes

The urethanes are the newest of the protective coating materials which are being tested for use on sewer structures. Published information indicates that this material has good solvent, salt water, and chemical resistance and has excellent general physical

properties. The flexibility and hardness of the urethanes can be varied over a great range.

More experience is required before an evaluation can be made of this material's potential uses.

There are numerous other coatings which have been in common use for many years. Since much information is available on coatings such as asphalts, oil paints, coal tars, and others they were not included in this paper.

TIPS AND QUIPS

Sludge Drying

The 1956 report of the Birmingham (England) Tame and Rea District Drainage Board contains some interesting results on a sludge drying experiment underway at the Board's sludge treatment works. The investigation is in connection with the possible lifting of dried sludge from open beds by machine. In determining the feasibility of machine lifting the need arose for information on the most economical depth to which wet sludge could be applied. An application of 18 in. of sludge, drying down to 6 to 9 in., while suiting the existing method of hand lifting on a bonus system, would yield a greater depth than could be handled by the machine in mind.

To observe the effect of various depths of wet sludge on the rate of drying 12 experimental beds, each 10 by 20 ft at the base, were constructed. The depths of sludge used were 6, 9, 12, and 18 in. It was arranged that as soon as sludge in one set of each of the four depths was sufficiently dry it would be lifted and refilled with the same depth of sludge. The remaining beds were to be used for making comparisons between the time taken for the drying of different depths of sludge put on the beds at the same time, and for comparisons with sludge dried on nearly half-acre beds of similar construction. In the 203 days required to dry the 18-in. depth of sludge, three successive applications of 6- and 9-in. depths and two applications of 12-in. depths of sludge were dried. However, the dry matter in one lift at each of the shallower depths was found to be only 33 per cent or less. The depth of dried sludge was difficult to measure with good accuracy. Approximately 1 to 1½, 2, 3, and 5½ in. of dried sludge were obtained with 6-, 9-, 12-, and 18-in. depths of wet sludge, respectively. The first tentative conclusions of the investigators were that a 50 per cent increase in volume of sludge dried is obtainable by filling to 9-in. depth and a 33 per cent increase with a 12-in. depth. No advantage was obtained by using a 6-in. depth.

If further observations confirm these conclusions it would indicate that the extra rate of drying of sludge in shallow layers is outweighed by the extra cost of lifting. In machine lifting, application of a 6-in. depth is thought to be a maximum.

Over the period of operation of the experimental beds it is estimated that the rate of air drying has been three times as great in summer as in winter.

Other experiments have been conducted to measure the quantity and quality of underdrainage from drying beds. The liquor collected was clear and colorless but amounted to only 11 per cent of the total in the sludge. Irrespective of the depth of application of the sludge, drainage took place only within the first few days. Thereafter

an insignificant amount of water was released. The investigators point out that sludge drying depends for the most part on evaporation and that climatic conditions have greater influence on drying than the underdrainage of the beds.

Kanawha River Survey *

What does West Virginia's basketball prowess have in common with pollution control in that state? Maybe nothing—but from all appearances it seems that the tactic of "double teaming" was used in a recent survey of the Kanawha River.

Last summer 12 industrial firms, the U. S. Geological Survey, and the State Water Commission joined forces and collected 1,500 samples during a 27-day period. About 5,000 analytical determinations were made. Sampling was done almost entirely by personnel from industry; most of the laboratory work was done by the Commission; and the Geological Survey was responsible for collecting most of the stream flow data.

The purpose of the survey was to determine what each industry must do as its part in cleaning up the Kanawha River. The tasks remaining are to correlate the new data with older data and evolve a plan of action.

Industrial Pollution Abatement

If you were asked the question, "Are industries reducing their pollution loads mainly by building treatment plants or are they doing it through in-plant changes?"—how would you answer? Well, in the December issue of *The Conduit*, the newsletter of the Virginia Industrial Wastes and Sewage Works Association, it is pointed out that, by far, in-plant changes are responsible for the greatest pollution reductions.

For example, five Virginia plants making viscose rayon or cellophane, or both, reduced their combined BOD load by 48 per cent. In 1946 the BOD load from these plants totaled 43,950 lb/day; in 1954 the load was 22,900 lb/day. During this same period 12 pulp and paper mills reduced their load by 42 per cent. These reductions were made despite production increases at most plants. Some of the reduction in the pulp and paper mills was accomplished by installation of industrial waste treatment facilities, but all the reduction at the rayon and cellophane plants was made by in-plant changes.

By-Product Recovery †

Special chemical compounds called Orzans are being produced from sulfite pulping liquors that otherwise might be wasted. The Lebanon, Ore., plant of the Crown Zellerbach Corp. produces Orzan A, used in wallboard manufacture; Orzan S, used in concrete; Orzan P, used as asphalt emulsifier; A H_3, an ore flotation agent used in molybdenum recovery; and $Greenz_{28}$, a leaf spray used to combat iron deficiency in trees and plants.

Plant Grounds

At Jackson, Mich., the sewage treatment plant grounds are known as Northlawn Park. Forty picnic tables are located there and on many occasions all are in use. Recently the Grand Trunk Railroad presented the city with a steam locomotive which will be placed on the plant grounds for all to enjoy. All of this adds up to a fine public relations job on the part of Superintendent R. A. Greene. Now that Mr. Greene has a whistle we hope he won't forget to toot it every once in a while.

* *West Virginia Waters*, **3**, 3 (Sept. 1958).

† *Northwest Pulp and Paper News*, **1**, 1 (1958).

News and Notes

Of Persons and Activities in the Wastewater Field

A M Rawn recently retired from his post as Chief Engineer and General Manager of the Los Angeles Sanitation Districts. He served as fourth President of the Federation for the year 1943–44. Mr. Rawn was named to honorary membership in ASCE at its October 1958 meeting.

M. B. Nixon, who for the past 15 years has been Engineer In Charge of Sewers for the City of Atlanta, Ga., has recently been promoted to the position of Assistant Chief of Construction for the City. Among his new duties will be the supervision of planning and construction of Atlanta's new three-year, $11 million sewer system and treatment program.

Thomas T. Quigley has been elected Vice-President—Equipment Divisions, Wallace and Tiernan, Inc., Belleville, N. J. He has been on the Federation Board of Control as a Director representing the water and sewage works manufacturers for the past three years and has been on the Federation's Executive Committee.

G. Gale Dixon, Associate with Parsons, Brinckerhoff, Hall & McDonald, died suddenly in New York in December at age 73.

The University of Florida has designated its new research facilities as the "Earle B. Phelps Sanitary Engineering Research Laboratory," after the "Dean of American Public Health Engineers."

Professor Thorndike Saville is now the Director of the Science and Engineering Study Center of the University of Florida at Gainesville. He had recently been a member of the New York State Public Health Council. This vacated post was filled by the Governor's appointment of **W. H. (Pete) Wisely,** Executive Secretary of ASCE and former Executive Secretary-Editor of the Federation.

H. Loren Thompson, partner in Stevens and Thompson Engineers, Portland, Ore., has been named the 1958 "Oregon Engineer of the Year" by the professional engineers of Oregon. He is currently serving on the Federation Board of Directors representing the Pacific Northwest Sewage and Industrial Wastes Association.

Vernon T. Stack, Jr. has been appointed director of the new Consulting Division of **Roy F. Weston, Inc.,** Newtown Square, Pa. He was formerly with Union Carbide Chemicals Company.

W. H. Larkin, former Chief of the Water Pollution Control Section of the New York State Health Department's Bureau of Environmental Sanitation, has recently been appointed Assistant Executive Secretary of the New York State Water Poilution Control Board.

Dr. Robert S. Ingols, Professor and Head of the Public Health Department at Georgia Institute of Technology, was recently chosen Chairman-elect of the American Chemical Society's Division of Water, Sewage, and Sanitation Chemistry for 1959.

Earl Devendorf, after more than 40 years of service with the New York State Department of Health, has retired as Director of the Bureau of Environmental Sanitation.

Wm. Hunter Owen, former Assistant Director of the Division of Sanitary Engineering of the Tennessee Department of Health, has become associated with the firm of Barge, Waggoner and Sumner, Nashville, Tenn. He was Chairman of the Kentucky-Tennessee Industrial Wastes and Sewage Works Association for the past year.

W. W. Horner, senior partner in the firm of Horner and Shifrin, St. Louis, died recently at the age of 75.

Harry Pryor has joined the firm of J. Sanders Parker, Consulting Engineers, Nashville, Tenn.

Evan A. Angley, Superintendent of the sewage treatment plant at Marshall, Mich., died recently.

Book Reviews

Biological Treatment of Sewage and Industrial Wastes. Volume II. Anaerobic Digestion and Solids-Liquid Separation. Edited by Brother Joseph McCabe and W. W. Eckenfelder, Jr. Reinhold Publishing Corp., New York, N. Y. 330 pp. Price $11.50 (1958).

The volume is comprised of papers presented at the Conference on Anaerobic Digestion and Solids Handling, sponsored by Manhattan College, New York, April 24–26, 1957. It constitutes an informative record of the present status and the progress in the subject.

Individual chapter headings follow:

Part 1. Anaerobic Treatment

Septic Tank to Controlled Digestion.
Biochemical Bases of Anaerobic Digestion.
Basic Principles of Sludge Digestion.
A Bacterium Looks at Anaerobic Digestion.
An Evaluation of High-Rate Digestion.
Environment Control of Anaerobic Digestion with Gas Diffusion.
Mesophilic Anaerobic Digestion: Design and Operating Considerations.
Applications of Gas Chromatography, Conductivity and Potential Measurement in Sludge Digestion.
An Investigation of the Influence of Some Radioactive Isotopes on Sludge Digestion.
Thermophilic Anaerobic Stabilization of Pea Blancher Wastes.
Effect of Vegetable Oil and ABS on Anaerobic Digestion of Primary Sludge.
Treatment of Packing House Wastes by Anaerobic Digestion.
Anaerobic Digestion of Pulp and Paper Wastes.
Chemical and Hydraulic Characteristics of the Anaerobic Contact Process for Sewage Treatment.

Part 2. Sedimentation and Flotation

Sedimentation Process Fundamentals.
Evaluation of Laboratory Settling Data for Process Design.
Application of Fundamentals to Waste Treatment Sedimentation Design.
A Comparative Study of the Hydraulic Characteristics of Two Types of Circular Solids Separation Basins.
The Uniflow Tank—An Improved Settling Tank.
Inlet Diffusion Control of Vertical Flow Basins.
Flotation in Waste Treatment.
Application of Pressure Flotation Principles to Process Equipment Design.
A Mathematical Interpretation of Flotations for Solids-Liquid Separation.
Studies on Dissolved Air Flotation of Biological Sludges.

Part. 3. Vacuum Filtration and Sludge Conditioning

Sludge Elutriation.
Laboratory Scale Filtration Experiments and Their Application to Sewage Sludge Dewatering.
Improved Sludge Conditioning and Vacuum Filtration.
Vacuum Filtration Principles and Their Application to Sewage Sludge Dewatering.

R. E. Fuhrman

The Municipal Year Book, 1958. By Orin F. Nolting and David S. Arnold, Editors. International City Managers' Association, Chicago, Ill. 598 pp. Price $10.00 (1958).

Highlights of the 1958 edition include special sections on municipal debt and public improvements planned in finance for the next 5 years. The municipal debt section presents the latest issues of general obligation, revenue, and special assessment bonds issued in 1957 by 550 cities over 10,000 population and shows the dollar amount of bonds issued for sewers and other improvements.

There are other new sections and the Year Book has been brought up-to-date.

R. E. Fuhrman

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Proceedings of Member Associations

OKLAHOMA WATER, SEWAGE AND INDUSTRIAL WASTES CONFERENCE

The 9th Oklahoma Industrial Wastes Conference was held at the Student Union on the campus of Oklahoma State University, Stillwater, Okla., September 24–25, 1958. Primary interest in the full 2-day program was centered around the petroleum industry waste problems; however, nearly half of the program drew attention to other industrial waste problems.

The program included the following papers of industrial wastes interest:

"Industrial Waste Disposal by Spray Irrigation," by Robert A. Canham, Associate Editor of *Sewage and Industrial Wastes*, Federation of Sewage and Industrial Wastes Associations, Washington, D. C.

"Progress of Pollution Control in Oklahoma as it Pertains to the Oil Industry," by W. J. Marshal, Corporation Commission, Oklahoma City.

"Controlled Air in the Activated Sludge Process," by Carl D. Wright, Pacific Flush Tank Company, Chicago, Ill.

"Aspects of Biological Waste Treatment," by A. J. Kress, President of Reliance Chemical Corp., Houston, Texas.

"How one Refinery is Handling its Waste Treatment Problems," by Roy D. Umbauch, Chief Chemist, Phillips Petroleum Co., Okmulgee.

(*Continued on page 64a*)

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"Progress of the Oklahoma Refiner's Waste Control Council," by M. E. McMahon, Engineer, Phillips Petroleum Co., Bartlesville, with a discussion by Troy Dorris, Professor of Zoology, Oklahoma State University.

"The New Oklahoma Water Resources Board," by Francis J. Borelli, Director, Oklahoma Water Resources Board, Oklahoma City.

"Water Quality Conservation Studies in the Arkansas-Red River Basins," by Keith Krause, Assistant Regional Engineer, USPHS, Dallas, Texas.

"Industrial Waste Disposal on Pryor Creek," by Jack Slater, Chief Analytical Chemist, Deere Chemical Co., Pryor.

At the business meeting of the Industrial Wastes Section it was voted to rejoin the water and sewage group after several years of separate meeting dates. This would begin with a combined meeting at the Water and Sewage Short Course in November of 1959.

Donald F. Kennedy, Project Engineer, National Gypsum Co., Pryor, Okla., was elected to serve as Director of the Industrial Wastes Section for the following year.

H. M. CRANE,
Secretary-Treasurer

PACIFIC NORTHWEST SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 25th Annual Meeting of the Pacific Northwest Sewage and Industrial Wastes Association was held at the Davenport Hotel, Spokane, Wash., September 25–27, 1958. Approximately 230 members and 42 wives were registered.

The technical program was excellent and well balanced. One afternoon was devoted to concurrent sessions. Highlights of the program included a

(*Continued on page 66a*)

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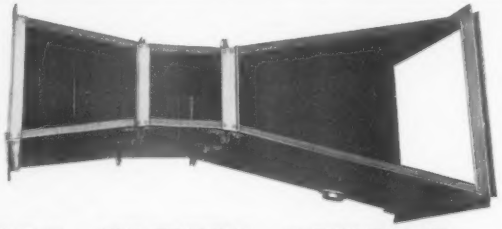

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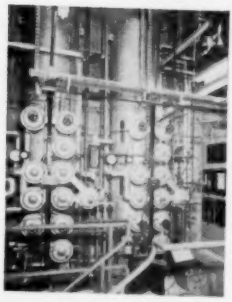

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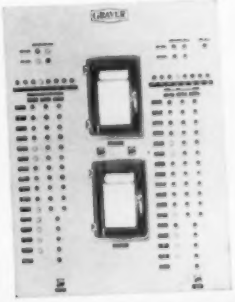

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luncheon address entitled "Public Relations and Industrial Wastes—Are They Miscible?" by C. Montgomery Johnson, Weyerhauser Timber Co., Tacoma, Wash. and an operators' round table, moderated by Ray Fish, Superintendent, Sewage Treatment Plant, Medford, Ore.

The popular annual breakfast and "bull session," moderated by R. T. Smith, Division Manager, Wallace and Tiernan Co., Seattle, Wash., was well attended. The field trip to the Spokane sewage treatment plant was interesting and instructive.

Panel-type presentations were used extensively and to great advantage throughout the technical program.

At the annual banquet Kenneth S. Watson, President, Federation of Sewage and Industrial Wastes Associations, discussed the "Challenges Facing a Mature Federation."

The Bedell Award for extraordinary service to the Pacific Northwest Association was presented to Robert O. Sylvester, Professor of Sanitary Engineering, University of Washington, Seattle, Wash. The Hatfield Award for the outstanding report in the field of sewage works operation went to Andrew J. Wahl, Superintendent of the Sewage Treatment Plant, Boise, Idaho.

At the business meeting the following officers were elected to serve in 1958–59:

President: Marvin W. Runyan, Portland, Ore.

Vice-President: Robert O. Sylvester, Seattle, Wash.

FSIWA Director (1961): H. Loren Thompson, Portland, Ore.

Secretary-Treasurer: Gilbert H. Dunstan, Pullman, Wash.

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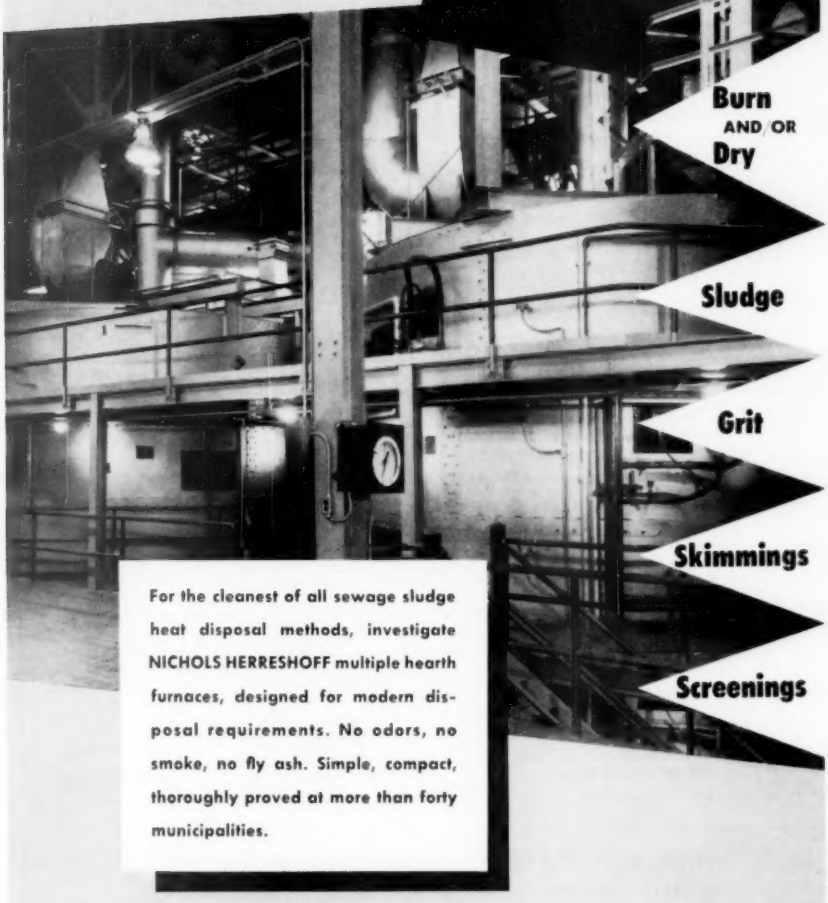

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INDEX TO ADERTISERS

	Page
American Cast Iron Pipe Company	50a
Armco Drainage and Metal Products	63a
B-I-F Industries, Incorporated	Inside Front Cover
Cast Iron Pipe Research Association	58a, 59a
Chicago Pump Company	39a
Combustion Engineering (Raymond Division)	43a
Dorr-Oliver Incorporated	60a
Filtration Equipment Corporation	64a
Flexible Incorporated	78a
Graver Water Conditioning Company	65a
Homestead Valve Manufacturing Company	51a
Inertol Company, Incorporated	56a
Infilco Incorporated	48a, 49a
Keasbey and Mattison Company	52a
Lock Joint Pipe Company	Inside Back Cover
Nichols Engineering and Research Corporation	67a
Pacific Flush Tank Company	41a
Simplex Valve and Meter Company (Subsidiary of Pfaudler Permutit Incorporated)	45a
Tennessee Corporation	66a
United States Pipe and Foundry Company	54a, 55a
Vapor Recovery Systems Company	61a
Vulcan Materials Company (Concrete Pipe Division)	47a
Walker Process Equipment Incorporated	57a
Western Machinery Company	62a
Wallace and Tiernan Incorporated	Back Cover
Yeomans Brothers Company	53a

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